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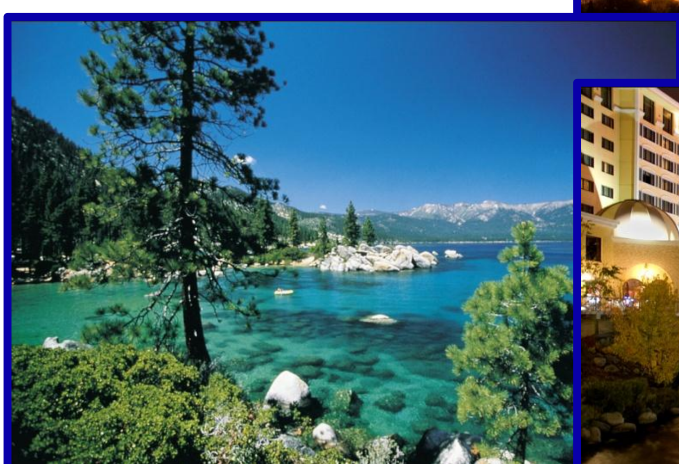
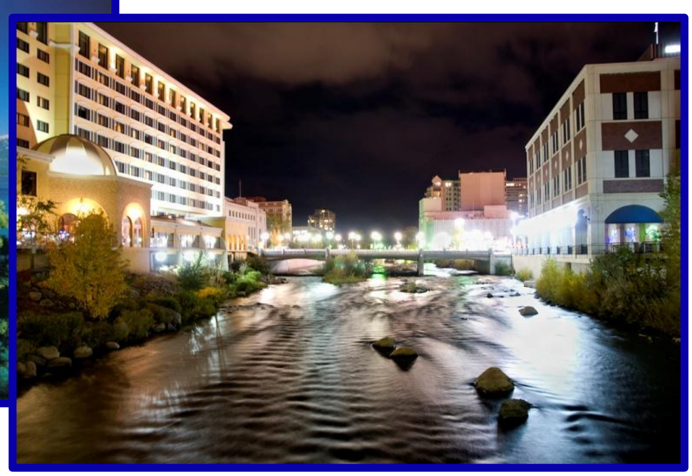
Proceedings





Educating Engineers in the Wild, Wild West

Hosted by the University of Nevada, Reno

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Bicycle Frame Building for Engineering Undergraduates

Kurt Colvin, Ph.D., P.E. and Jim Kish
Cal Poly, San Luis Obispo / Kish Fabrication

Abstract

The common safety bicycle design first appeared in Brittan in the 1870s. In the 130 years since, engineers and craftsmen have created hundreds of new bicycle designs, fabrication methods, materials and components. However, the simplistic diamond frame design has survived, is still commercially available and fully functional. The bicycle itself provides a rich learning platform in which to illustrate topics such as design, manufacturing process planning, tooling, materials, and the design/build process. This paper gives a status report on the development of a course that teaches engineering undergraduates the process of building a bicycle frame. Learning opportunities are described and methods and equipment are briefly explained. This is a work in progress.

Introduction

The intent of this course is to teach relevant engineering topics through a project-based course[1] that engages and motivates students. Each student enrolled in the course plans, designs, fabricates and inspects a custom-fit bicycle frame. The course was initiated by the authors after a discussion on the benefits to engineering students of the process and skills required to build a bicycle frame.
The course development process was started in January of 2009 by obtaining funding for initial curriculum development, materials and required tooling. The course was designed and developed using backward design.[2] The steps in backward course design are: (1) identify the desired results, (2) determine the acceptable evidence, and (3) plan learning experiences and instruction (See Figure 1.). By focusing on the end results first, course developers can help students to see the importance of what they are learning and make our activities more meaningful and based less on what we have seen others do or how we were taught.

Figure 1. Backward Course Design

While there are many interesting and exciting engineering design and fabrication opportunities possible with bicycles, our experience has been an open-ended project can quickly become complex and difficult to achieve learning outcomes (and completed projects) in a 10-week course: Therefore, we narrowed the objective of this course to design and build a conventional, straight-stay, chromoly bicycle intended for road use. This specificity was established to limit both the simplicity of the fabrication methods and the variety of tooling required to build the frames.

The remainder of this paper describes application of the backward course design process, briefly explains the steps in the design-build process and identifies an inherent challenge with continued offering of this course.

Identify Desired Results

Similar to the importance of establishing a problem statement and set of requirements for any engineering endeavor, the desired results for a course must be explicitly established. This statement then, is the ultimate objective of the course:

Each enrolled student shall deliver a custom-designed, chromoly tube road bike frame of sufficient quality to perform as well as a commercially-purchased steel bicycle frame.

In terms of student learning, the authors have developed the following list of learning objectives that we suggest would be beneficial to the education of engineering undergraduates:

- *The ability to define and use relevant vocabulary*
- *The ability to translate anthropometric data into a design*
- *The ability to create a dimensioned drawing with all required information*
- *The ability to understand the interrelatedness of design and manufacture*
- *The ability to apply tolerancing concepts to an assembly*
- *The ability to inspect and rework to meet a tolerance specification*
- *The ability to evaluate acceptable overall quality*
- *The ability to work closely in a resource-limited environment*
- *Experience the challenges and complexity of manufacturing*

While it could be argued that these learning objectives are manufacturing or mechanical engineering-specific, at Cal Poly, we strongly believe all engineering graduates should have practical, hands-on experience with fabrication techniques. ABET assessment criteria suggest students would benefit from experience with concepts such as tolerancing, creating engineering drawings, evaluation of quality and working together in a resource-limited environment.[3] These are universal engineering concepts, applicable to all engineering majors. In this project-based learning experience, we have selected a topic (bike frame manufacture) that interests students, yet provides a rich milieu to accomplish the list of learning objectives above.

Determine Acceptable Evidence

Following the backward course design process, the next step is to determine acceptable evidence that the learning objectives have been achieved. In this case, to achieve the ultimate objective of this course (*deliver a usable bicycle frame)* all of the learning objectives must be met with at least acceptable evidence. One of the advantages of project-based learning experiences is that achievement of the learning outcomes is inherent in the definition of the project.[4,5] In other words, it is virtually impossible to complete the objectives of the course without achieving the intermittent learning outcomes.

Since each student enrolled in the course is required to build their own frame, it ensures that each student is held accountable for achieving each of the identified learning outcomes. For example, if a student generates a drawing missing a critical dimension for fabrication, he cannot continue until the omission is rectified and the drawing corrected. As instructors our assessment activities are well-defined, objective and readily accomplished.

Learning Experiences and Instruction

Finally, the last step in the backward course design process is to develop the learning experiences and instruction to achieve the desired results. The following sections briefly describe the distinct activities required to achieve the learning objectives. They are outlined here to give a general sense of the course activities. These lessons equate to the ten, 5-hour lab meetings of the course.

1. Bicycle frame building terminology, processes and skills
Students are introduced to the history of the bicycle, frame and component terminology, joining methods, basic machining and shop safety.

2. Design frame and create frame drawing
Students learn how to properly take body measurements to fit an individual to a custom frame. After they have gathered the appropriate measurements, a short lecture on the geometry of a standard road frames is presented. Once the anthropometric measurements have been translated into a basic design, the students create a frame drawing.

3. Seat tube subassembly preparation and welding
The seat tube is rough cut to length then mitered to fit the bottom bracket shell and fully welded.

4. Front triangle preparation
The remaining front triangle tubes (head tube, top tube and down tube) are issued. Required machining processes are performed. Every dimension is verified as any errors at this stage translate to poor fit-up once the tubes are fixtured for welding.

5. Front triangle fixture, tack and weld
The front triangle tubes are now dressed, sanded, degreased and fixtured in preparation for welding. If any joints have out of tolerance gaps, the tubes are hand-filed to improve the fit. Once the tubes fit properly in the fixture, the tubes get a final cleaning and are tack welded. The main triangle is then removed from the fixture and fully welded.

6. Rough cut and miter chainstays
The rear triangle (dropouts, chainstays and seatstays) of the frame is built as separate subassembly. The chainstays are prepared and mitered. This is a delicate and time-consuming process.

7. Rough cut and miter seatstays
The seatstays are dealt with similarly.

8. Fixture, tack and weld rear triangle
Once all the rear end members are mitered, sanded and cleaned, the front triangle is put back into the main frame fixture along with the rear triangle tubes. Once all joints are tacked on their centerlines,

the frame is removed from the fixture. The alignment of the frame is checked and corrected if necessary. The rear triangle is then fully welded on a bench and the alignment checked for a final time.

9. Select, prepare and braze on small fittings and bridges
The rear brake bridge is machined, prepared and brazed. Shift bosses and cable stops are installed. Fittings to attach racks and fenders can also be integrated, if desired.

10. Prepare frame surfaces for components and painting
The final stage is to prepare the frame to accept all of the components. The frame gets a final quality inspection and any rework is completed before it is sent to be powder coated.

Course Development and Continued Offering

Course Development
The course was designed to accommodate ten students with two instructors. The low instructor-student ratio is necessary to assist students with intricate tooling, fixturing and welding tasks. There is also significant equipment setup and tear down time, as our labs are not dedicated to frame building and have many other classes being taught throughout the academic term.

Our costs to develop the course were roughly $10,000 ($6,000 in tooling and $4,000 in salary). This does not include the following required equipment used in the course that was already present in our manufacturing engineering labs:

- 10 TIG welders
- 3 milling machines
- 1 engine lathe
- 1 drill press
- 1 belt sander
- 1 oxygen-fuel torch cart

Continued Course Offering
We have designed the course to be offered in weekly 5-hour lab sessions over a 10 week academic quarter. The 50 in-class hours are roughly divided into 30 hours of instruction and practice and 20 hours of build time.

The costs to offer the course to 10 students per term on a reoccurring basis would be approximately $9,500 per term, broken down as follows:

• 10 Bike frame building kits:	$1,000
• Outsourced powder coat of 10 finished frames:	$ 500
• Miscellaneous supplies and expenses:	$ 500
• Two instructors (2 x $75/hr x 50 hrs)	$7,500
Total:	$9,500

The bike frame class has been offered twice at Cal Poly: First, funded by college-based student fees (which are no longer available) and a second time by a large fee assessed on the enrolled students. We find these options neither attractive nor sustainable. The course is not scheduled to be offered again.

Conclusion

The construction of a simple conventional bicycle frame provides a rich learning opportunity for engineering undergraduates and the students are tremendously enthusiastic about the course. It develops very specific building skills (i.e., welding and machining) and more generalized engineering skills (i.e., design, common manufacturing processes and quality assessment). Further, it fosters a team-based atmosphere and the students' enthusiasm for the project builds quickly. It has been a unique teaching experience for the authors. Finally, as educators, we've found the nature of the project-based learning makes assessment of the learning objectives inherent in the students' work. The students understand from the first day of class that success in this course is defined by delivering a usable bicycle frame by the end of the course.

In the two offerings of this course, all 20 students have completed their frames to at least an acceptable quality level. The informal student feedback has been overwhelming. All report having achieved the ultimate objective of completing of their frame. Word of the bike frame building class has spread among the students and we have weekly inquiries about how and when the course will be offered again. Many inquiries come from non-engineering students.

While this is an expensive course to offer, we feel it has a legitimate set of learning objectives that are beneficial to engineering undergraduate students. It closely follows Cal Poly's learn by doing philosophy and it is a very enjoyable experience for both the students and instructors.

In conclusion, about half of the students have invested their own money to purchase components (forks, wheels, brakes, etc.) to complete their bicycles. Several times we have encountered students on campus riding their hand-built bicycle. It is very apparent how proud they are to have built their own bicycle.

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GIRLS SEE Summer Camp: An Event for Future and Current Female Engineering Students

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Abstract

This paper describes the inclusion of the California State University, Fresno (hereafter referred to as Fresno State), Society of Women Engineers (SWE) chapter in the organization and implementation of the GIRLS Summer Engineering Experience (GIRLS SEE) summer camp. GIRLS SEE is a recruitment and retention effort from the Lyles College of Engineering at Fresno State to increase the number of female applicants into the different disciplines of engineering and to increase retention of the current female engineering students. The second objective is accomplished by providing female engineering students with a service learning experience by assisting in the administration of the camp and mentoring the participants.

The GIRLS SEE camp is designed to expose the participants to all six of the disciplines taught in the Lyles College of Engineering (Computer Engineering, Construction Management, Electrical Engineering, Geomatics Engineering, Civil Engineering and Mechanical Engineering), and increase the number of female students in STEM related majors. During five days, girls entering 10^{th}, 11^{th} and 12^{th} grades from several local high schools participate in activities designed by engineering faculty to gain a basic knowledge of the different disciplines.

Each of the SWE student volunteers is trained in all of the activities, whether they are specific to her selected discipline or not. During the camp, the SWE volunteers assist the faculty in charge of the activity and offer direct support to the high school students. In addition, the volunteers are asked to give at least one presentation and lead team-building activities during the camp, with the intent of helping them develop leadership skills.

Surveys are given to the high school students as well as to the SWE volunteers to assess the success of the camp. Both groups of students are invited to participate in follow up events and surveys. The authors intend to perform further investigation to verify the effect of the summer camp on recruitment and retention.

Introduction

The GIRLS SEE summer camp was conceived in response to the latent concern for the small numbers of female engineering students which would translate into low numbers of females in the labor force in technology areas. A study showed that by 2007 the percentage of undergraduate female engineering students had decreased to only 17 percent[1]. At Fresno State only 14.2 % of the students receiving an engineering degree during the academic year 2007-2008 were female[2]. In addition, as seen in Figure 1, retention of first year female engineering students at Fresno State is at its lowest level since Fall 2002.

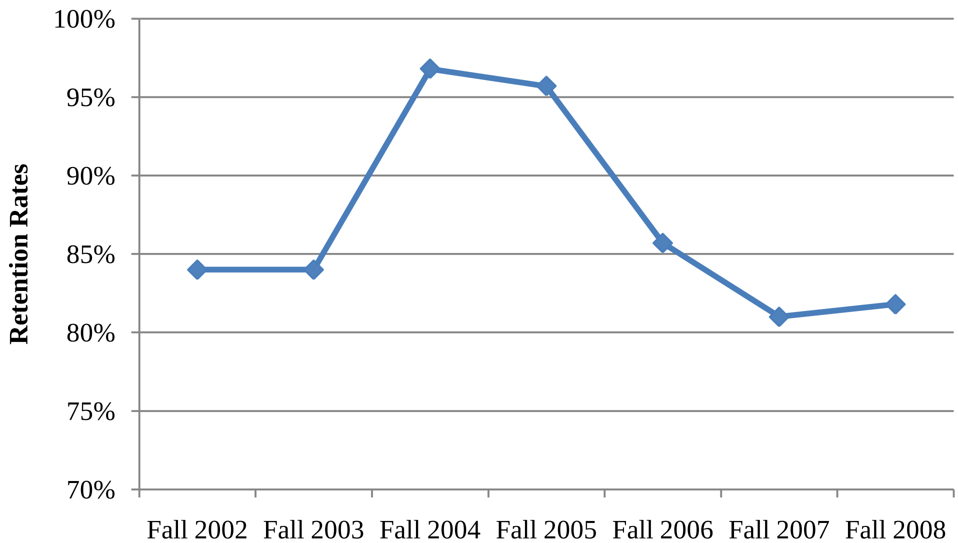

Figure 1. Retention rates of first year female engineering students at Fresno State[3]

Several efforts to address these issues have been reported. The University of Arkansas successfully hosted an Engineering & Summer Day Camp for Middle School girls to raise awareness and create enthusiasm for the science and engineeringdisciplines[4]. The Girls Reaching and Demonstrating Excellence (GRADE) camp was hosted by the University of Houston Cullen College of Engineering where faculty and Society of Women Engineers (SWE) mentors guide high school girls through engineering activities[5]. At Purdue University a student group called Women in Technology invited a group of high school girls to expose them to the various majors in the School of Technology[6]. Furthermore, a study shows that the Science Technology and Engineering Preview Summer Camps (STEPS), designed to address the critical shortage of women in STEM related careers, show promise in addressing this national shortage[7].

The authors believe that it is necessary to create local programs such as those mentioned before, aimed at exposing female students in their final three years of high school to basic concepts within different areas of engineering and construction management to open the possibilities for these students to choose a technical major.

Since retention of students is another major concern, the camp was designed in such a way that current female engineering students can participate as mentors and assistants for each activity. The faculty in charge of the different activities trained the students, providing a service learning experience and giving leadership opportunities to them.

Description of the Camp

The camp was designed as a non-residential activity to provide information about all six disciplines offered at the Lyles College of Engineering at Fresno State: Computer Engineering, Construction Management, Electrical Engineering, Geomatics Engineering, Civil Engineering and Mechanical Engineering. The camp took place on campus during five days (Monday through Friday) from 8:30 am to 4:00 pm, and 23 female students from five local high schools participated. As mentioned before, the activities were designed and supervised by participating faculty members but female students from the Fresno State chapter of the Society of Women Engineers (SWE) were on hand for all activities. They provided guidance and support when needed by the participants. Additionally, engineering students served as mentors to the high school students. Frequently, the high school participants directed questions and comments to the engineering students in lieu of speaking to the lecturers in front of the entire group. Technical speakers consisting of engineers from local industry and engineering faculty, four extensive hands-on activities and three field trips formed the week's curriculum.

Recruitment and Diversity of Participants

Recruitment of the high school participants in Girls SEE was a collaborative effort between the GIRLS SEE faculty and staff organizational team as well as the female students in the SWE chapter. SWE students designed the informative brochure and fliers used for recruitment. This material was disseminated via e-mail to the Fresno State faculty and staff community, to local high school counselors, and to advisory board members who are employed at local companies. Face to face recruitment took place at local high schools. SWE students were paired with female faculty members to visit math and science classrooms at local high schools to talk about experience as an engineering student as well as the Girls SEE camp. Additionally, the Girls SEE organizational team coordinated with the Girl Scout Council of Central California South. The Girl Scout Council e-mailed the student designed fliers and brochures to their troop leaders ranging from Bakersfield to Fresno. Six participants were recruited from this collaboration. A lesson learned from the recruitment effort was to start the effort earlier in the calendar year. Standardized testing that occurs in California high schools in May made the in-class visits difficult to schedule.

Student applicants to the Girls SEE camp were required to submit a one-page personal statement and a letter of recommendation from a current teacher. The Girls SEE organizational team planned to accommodate 25 students. Only 23 students fulfilled the requirements of the application process described above and all of those students were accepted.

The composition of the student participants was varied. The breakdown of student participant by high school grade is shown in Figure 2 and the ethnic diversity of the students is shown in Figure 3.

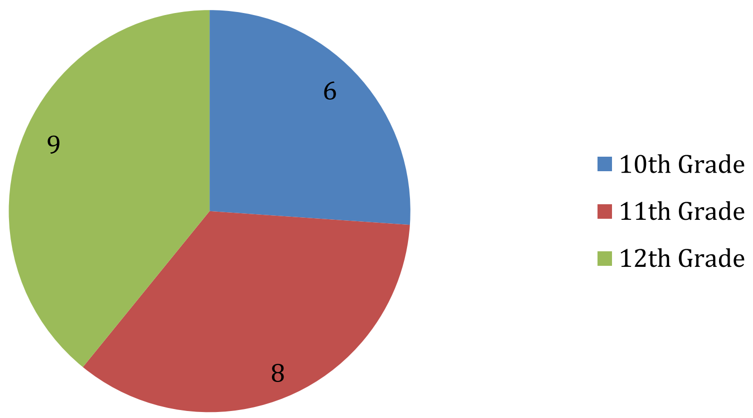

Figure 2. Distribution of Girls SEE participants by grade level

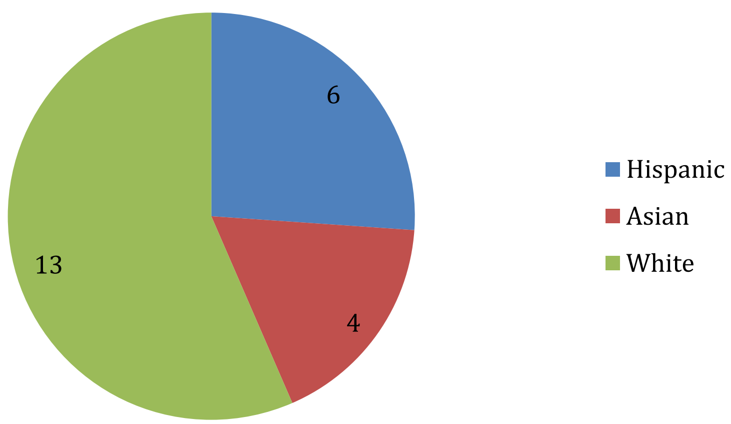

Figure 3. Diversity of student participants

Funding and Cost

The cost of running the Girls SEE camp was under $5000. The majority of funding was provided by the Lyles College of Engineering at Fresno State. Local industry donations as well as a donation from a Fresno State alumni amounted to $3000, which was used to pay for transportation to one of the field trips and a follow-up activity after the camp. These donations also have provided seed money for Girls SEE 2010. Costs for Girls SEE were kept low by faculty presenters and faculty on the Girls SEE organizational team donating their time and utilizing already existing material and resources in the Lyles College of Engineering for the hands-on activities. Participants were charged $150 per student for the camp. Eleven full scholarships were awarded to students demonstrating a financial need. Due to the fees associated with the University entity that administrates summer programs, the income from the paying participants' off-set the awarded scholarships and did not impact the budget for the program activities.

Activities

Hands on activities performed in the camp were 3 hours long which included a 20 to 30 minute introductory lecture prior to commencement. Exceptions to this schedule included the robotics activity and the "I measure for treasure" activity. The "I measure for treasure" activity included a 30 minute introductory lecture presented by a Lyles College of Engineering Geomatics Engineering Professor prior to the 3 hour activity that was led by industry members from Pacific Gas and Electric (PG&E). The robotics activity covered concepts in Electrical and Computer Engineering as well as Mechanical Engineering. The introductory lecture to the robotics activity included faculty from both of those departments and took approximately an hour in addition to the three hour time slot for the activity.

Solar activity

Students were introduced to a variety of solar energy technologies through a multi-media presentation by Geomatics Engineering professor Dr. Fareed Nader. Photovoltaic panels as well as solar towers were shown and discussed. Following familiarization of these solar techniques, the students were introduced to a solar pathfinder. The pathfinder is used to perform solar site analysis and has been the industry standard to determine the impact of shade on the placement of solar panels. Additionally, the solar pathfinder can predict the amount of sunlight that the selected site will experience all year. The components of the solar pathfinder include a dome that provides a panoramic view of the site reflected on the dome's surface. A paper sun-path diagram showing the sun's route through the sky for every month of the year and every hour of the day is underneath the dome. Broken into teams of four students, the solar path finder was placed in different positions in front the engineering building. A digital camera was used to take a photo of the sun-path diagram; shade will result where there are objects that impact the sunshine. The photo was then analyzed by software to determine the percentage of solar efficiency that the site has to offer. Students performed the analysis using this software and then printed out their diagrams. Figure 4 shows a group of students studying the Solar Path finder with the help of Dr. Nader and the lab technician, Steve Scherer.

Figure 4. Students during the solar activity

"I measure for treasure"

An introduction to geomatics engineering was presented by Dr. Riad Munjy, a professor in the Civil and Geomatics Engineering Department. Students were introduced to three-dimensional mapping and global position systems. Following the geomatics lecture, a team of female geomatics engineers employed by PG&E were introduced. The majority of these female engineers were also alumni from the Lyles College of Engineering at Fresno State. This team of women shared their experiences from their careers at PG&E as well as introduced students to the technical equipment that is used in land surveying. The culmination of the geomatics activity was when the students were combined into teams of four and given the opportunity to use land surveying equipment provided by PG&E. Each student was provided coordinates where a 'treasure' was buried on the Fresno State campus. Assisted by the professional engineers, students used angles and distances to determine where the treasure was located. All treasures were retrieved successfully by the students. Figure 5 shows a team working with a geomatics engineer during the activity.

Figure 5. Camp participants working with PG&E engineers

Robotics activity

To explore robotics and other concepts in electrical and mechanical engineering, the students were combined into teams of two and three and provided a Lego™ Mindstorm NXT robotics kit. Following instructions provided to them, the students were allowed to explore the mechanical intricacies of assembling the robot. Several teams were required to improvise and troubleshoot as an error was made in assembly or different pieces than advertised were included in their kits. Following assembly, the students were asked to use the NXT brick, the 'brain' of the robot, to create a simple program. The NXT brick's have object-oriented programming capability that allows five commands to be programmed and executed. After familiarization with the programming language of the Mindstorm, the students were asked to investigate some of the sensors included in the kit by following instructions on connecting the sensors properly and verifying their correct operation. The integration of the sensors into their projects was communicated as 'Missions'. Mission 1 was to create a light sensing robot. The two tasks that were required of the robot were to maintain a perimeter around a black piece of paper and to turn if the robot encountered a flash light beam in a darkened room. The tasks of this mission required use of a Lego™ light sensor that provided a digital output based on the amount of light.

Mission 2 was to build a robot that will only move forward when a clap is heard. A microphone was used by the students to accomplish this mission. The last part of this mission required that the students program the robot to emit a sound when a clap is detected. The final mission (Mission 3) required the use of a touch sensor. The robot was required to reverse when it bumped into a wall. The majority of the student teams were able to complete all missions as well as apply their own creativity and experiment with both the assembly and the programming of the robot. Figures 6(a) and (b) show students in during the robotics activity.

(a) (b)

Figure 6(a) and (b). Students working on their robots

__Balsa wood structure__

The students were given a lecture by Dr. Jesus Larralde regarding basic principles in building sound structures and then given a tour of the structures laboratory in the Lyles College of Engineering. Two balsa wood towers with different elements of building design were placed upon a large shaker table to illustrate the effect of an earthquake upon a multi-storied building. The students were able to visually determine which building design was more resistant to the effect of earthquakes. Students were then combined in teams of five and tasked with creating a structure to support a solar panel. The only specifications given to the students were that the structure had to be composed of balsa wood pieces and hot glue and that it needed to be a certain height. Students were provided engineering paper to design the elements of their structure. It was evident that the student teams applied the knowledge gained from Dr. Larralde's introduction, as braces were included to strengthen square or rectangular components. A small weight was placed on the top of the structures and a portable shaker table was brought to the classroom to test the student designs. Simulating the conditions of an earthquake, the use of the small shaker table tested the structural integrity of the structures. All structures developed by the student teams withstood the test. In Figure 7, a team is showing their final structure accompanied by Dr. Larralde.

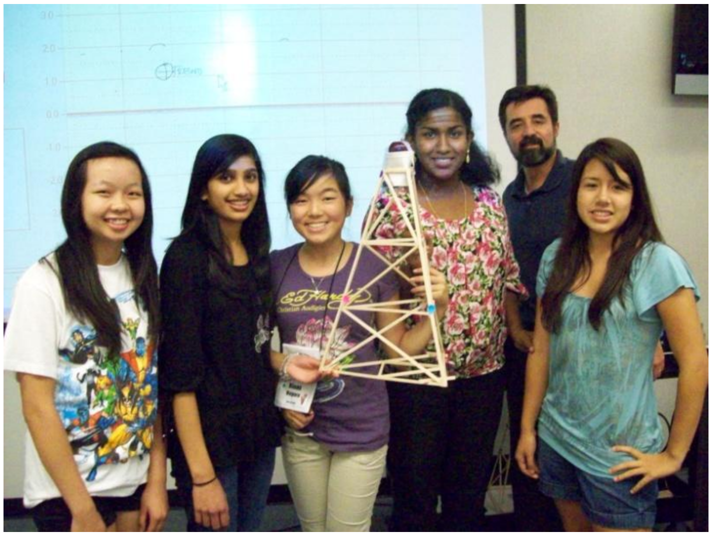

Figure 7. Participating students displaying their balsa wood structure

Field trips

In addition to the hands on activities, the students were taken on three field trips to expose them to various local industries that employ engineers and to see what engineers do on the job. The first visit gave the students a first-hand impression of the practical aspects of the construction management discipline. They visited a newly constructed local church to view an example of how modern "green" construction techniques are implemented and discuss their importance. The second trip took the participants to Gallo Winery in Modesto, California. This visit demonstrated the integration of electrical, industrial, and mechanical engineering concepts in the design, construction, and operation of an automated assembly line used in the bottling of wine. Finally, the participants visited a local pump manufacturer, Weir-Floway, where they were given a tour of the facility and were able to talk to engineers working on the design and fabrication of various hydraulic pumps.

Presentations and other activities

A keynote speaker was invited to give a presentation to the students during the first day of the camp. This presentation was a descriptive lecture providing an overview of engineering and what a student should expect after graduating from an engineering major, and first-hand accounts of being a female engineering student and professional. Also, senior students from all engineering disciplines were invited to be part of a student panel. During the panel, the camp participants were able to ask current students about the life of an engineering student at Fresno State. The participants also engaged in a team building activity and a tour of the new library facilities at Fresno State.

Survey Results

To assess the possible benefits to the recruitment and general student response, a survey was prepared and mailed to all 23 participants. Ten responses were received and are summarized below. The results are summarized in Tables 1 and 2.

Table 1. Responses to yes or no questions on survey

QUESTION	YES	NO
Were you considering engineering as a major before attending GIRLS SEE?	5	5
Now that you have been exposed to engineering, are you considering engineering as a major in college?	10	0
Would you be interested in follow-up activities for GIRLS SEE 2009 participants? They may be technical or social.	9	1
Would you be interested in being in a GIRLS SEE 2009 Facebook group?	7	3
Would you have preferred that it be a residential camp instead of a day camp?	6	4

The students were asked to answer yes or no to six questions (shown in Table 1). As seen in Table 1, half of the students that responded the survey were unsure about becoming engineering majors, but after the camp all the students that responded would consider engineering as their major. It is interesting to note that the majority of the students would be interested in follow-up activities after the camp. This shows that the participants enjoyed their experience and created some sense of camaraderie. However, there is not a significance preference to change the format to a residential camp.

The participants were also asked to grade each of the activities of the camp (1-Poor, 2-Fair, 3-Mediocre, 4-Good, 5-Excellent). Table 2 shows the average and the standard deviation of the grades the students that responded to the survey gave to all the activities.

Table 2. Average and standard deviation of the grade given by the participants to the camp activities

ACTIVITY	GRADE	STANDARD DEVIATION
Keynote speaker	4.0	0.94
Solar activity	4.1	0.74
"I measure for treasure"	4.6	0.70
Robotics	5.0	0.00
Balsa wood structure	4.7	0.67
Student panel	4.6	0.70
Professional pizza lunch	4.0	0.82
Green building tour	3.2	1.40
Weir-Floway tour	4.3	0.67
Library tour	4.5	0.97
Gallo Winery tour	4.9	0.32

All the activities but one received scores between good and excellent. The highest averages correspond to the robotics activity and the visit to Gallo Winery. The lowest average was given to the visit to the "green" building. The organizers believe that this is due to lack of motivation and clarity of the presentation given by the tour guide.

Another survey was given to the current students with the intention of assessing the effect on retention and studying the effectiveness of the service learning experience. The students were asked to give a number based on their level of agreement or disagreement (1-Strongly agree, 3-Neutral, 5-Strongly disagree) to several statements. Since this is a work in progress the responses are considered anecdotal at best. The results of this survey are summarized in Table 3.

Table 3. Response to survey given to current students serving as assistants

STATEMENT	SCORES (AVERAGE)	TOTAL STATEMENT (AVERAGE)
I was familiar with the concepts before training/execution of		
a. Solar activity	4.75	3.875
b. "I measure for treasure"	4.5	
c. Robotics	2.25	
d. Balsa wood structure	4	
The knowledge/training provided for each activity was sufficient for me to feel comfortable leading the students through this activity		
a. Solar activity	5	4.625
b. "I measure for treasure"	5	
c. Robotics	1.75	
d. Balsa wood structure	3.75	
I gained engineering knowledge by assisting the students with this activity		
a. Solar activity	3	2.75
b. "I measure for treasure"	2.5	
c. Robotics	2	
d. Balsa wood structure	3.5	
By assisting the student participants in GIRLS SEE, I feel more confident about my engineering ability	3	-
By assisting the student participants in GIRLS SEE, I gained leadership skills and confidence as a leader	2.75	-

Table 3 shows that the students did not feel confident about their knowledge of the concepts involved in the camp activities. The survey shows that after their experience as assistants during the activities the students feel they have gained some leadership skills and confidence as leaders. However, they are neutral about gaining more confidence in their engineering ability. The organizers believe that more attention should be giving to the training of the current students to enhance the service learning experience.

Participants were also asked to comment on their experience during the camp. Some of the comments included:

"Attending the first Girls SEE camp has been a wonderful experience for me. Being introduced to a variety of careers in Engineering is what I liked the best. Also, the activities were really fun. For the whole week I attended this camp, it made me determined to pursue engineering as career."

"I really enjoyed coming to this camp. I met a lot of people and learned how to be more communicative. I have now more knowledge of what an engineer is. I really enjoyed building and I am really looking forward to do it next year. Thank you!"

"This camp provided much information about different career choices that are in the field of engineering. The guest speakers talked about their experiences and increased my interest in engineering. I liked the field trips because I got to see first-hand what the industry is all about. The camp is great because you can meet other girls who have similar interests in a positive environment."

"All I can say is that by participating in this camp made me think of engineering as one of the most exciting, challenging, and important careers imaginable. Also, girls should turn their ideas and dreams into reality. Girls will succeed in engineering by attending this camp because it gives them the information, determination, and courage of being a woman engineer."

"I can take a lot from this experience. I found that engineering is a great career where women are growing to play a role in the work industry. Listening to women in the profession gave me an insight on the impact women have in engineering jobs. I learned information about all aspects of engineering, and I will continue to pursue a career in this field."

Future work

The authors intend to use the results from surveys to identify the efficacy of efforts such as this. The organizers will attempt to track the effect of the camp on recruitment of new students and retention of current female students in engineering fields at Fresno State and other universities. Also, the authors will use a control group (students that did not participate in the summer camp) to compare with students that participated in the camp to study the effect of this type of events on student attrition.

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Work in Progress: Use of Video in Casting Education

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Abstract

Our traditional casting course features both lecture and laboratory venues. However it is noted that many students have never interacted with foundry equipment, and there is a significant learning curve associated with the ability of a student to execute basic green sand foundry operations. Education methods were sought to reduce this learning curve resulting in a series of short videos with subsequent incorporation into the curricula.

In this study, the use and effectiveness of video in a modified 'traditional' introductory casting course is explored. First, specific video equipment is listed, and the creation and editing processes described. Then the videos were used in casting classes, and the students were allowed access outside of class.

A positive educational impact due to the videos was evidenced by instructor and student feedback. A casting operations metric was presented, with measures including time-on-task analysis. A more rigorous pedagogical use and assessment of educational impact is planned for a class in the spring of 2010.

Introduction

Motivation for this project was to improve both the education experience and the speed at which students would acquire necessary skills and concepts. In a skills intensive course such as MET257 'Casting Processes', many 'millennial' students (1) are ill prepared. Specific skills include operational safety (e.g. use of PPE) and operations (e.g. sand preparation, molding).

The content of MET257 contains basic foundry processes such as 'green sand', and has laboratory exercises in an on-site green sand foundry. A typical foundry process includes management of the sand, as well as many tools (e.g. patterns, flasks) and equipment (e.g. furnaces, crucibles, test equipment). Overlaid on this complex environment are real safety issues. A significant amount of time is allocated to both skill development and related safety concerns.

An idea was developed to create videos that addressed these needed skills, concepts and issues. The videos would be used in the CWU Foundry, to supplement the introductory course (and other courses as needed). There was obviously no such material evident at CWU, but subsequent searches did turn up some similar material such as those from Georgia Tech (Jonathon Colton) on NDSL (2). There appeared to be limited use of external material due to the differences in equipment and procedures.

It is also noted that there was no substantive way to determine the ‘effectiveness’ of using video, in an education pedagogy sense. To address this a metric was created and planned for use in another course (also using the foundry).

Finally, the process of creating a video is time and equipment intensive. Some ancillary aspects of video production included a momentarily clean foundry, an outstanding archive document, and some of those higher Bloom’s Taxonomy (3) scenarios played out on the instructor.

Methodology

This project posits the use of video to accelerate and improve some basic foundry concepts and skills. Since safety is such a prominent constraint, it is covered soon and often. Commercial videos (4) have been used during MET257 in conjunction with lab tours and demos. But commercial scenarios are typically different in scope and application compared to the small foundry at CWU. So the videos we created use CWU facilities.

The first video created was a general foundry process description. The base footage was taken during an outreach event know as the ‘Pattern Swap’. The event is intended to foster support and networking for all foundry education entities in our region. It typically has 3-4 dozen attendees from all over the state, with all levels of K-20 represented. An attribute of this venue is that a variety of participants were available.

The next two videos targeted green sand. One video described the use and maintenance of the sand itself. The other video concentrated on how sand is used to make a mold. Managing sand is both a time-consuming and necessary part of foundry operations. Many students are reticent to approach and use the large equipment. There is also a quality issue (the quality of the sand itself) of interest.

The videos were created over the spring and summer of 2009. The first opportunity to use the videos was in a ‘Production Technology’ (MET345) course in the fall of 2009. The videos were included into the existing curricula.

During MET345 Production Technology (5), the foundry is used to cast metal propellers for toy aircraft. About 500 toys are made each year for the holidays. Each toy is made of donated wood and metal foundry parts. The ‘airplane’ has wood fuselage, wing, tail and wheels, with a cast metal propeller (advertising CWU and our Industrial and Engineering Technology Department). Major outcomes for this course are oriented toward production (e.g. production processes, process control, quality control). Since the actual wood or metal fabrication processes are secondary, there is reason to quickly gain the necessary fabrication skills. The videos were used for this purpose.

Video Issues

Creating a quality video is certainly becoming more doable. The advent of handheld HD camcorders (e.g. SONY HDR) allowed a team of two to capture the video during the Pattern

Swap event. After that a considerable amount of time was spent editing. This excessive editing time (orders of magnitude) may be unappreciated by non-participants. These videos were edited using Adobe CS4 Production software (6). Narration was overlaid later using a digital recorder (OLYMPUS VN-4100PC) and many e-mails.

Other content for the videos included a series of still pictures of the foundry that were shot during off hours. Also, some illustrations were developed to augment the video. These illustrations were done in MicroSoft™ PowerPoint (e.g. mold sequence). Hours went uncounted as the product was pushed forward to meet our deadlines (fall classes).

The video product has many qualities. Like images, there are different storage formats and compaction styles. Adobe™ was used as a master. Vimeo™ was used (www.vimeo.com) as a streaming agent (7). During class, the internet was accessed and Vimeo brought up. The videos were run from the Vimeo website. To view the videos, simple go to Vimeo and search for 'green sand casting', for example.

Many pitfalls exist in the creation of videos, such as the time involved. For the three videos described, there are many types of activities that occurred. For example, we estimate 20 hours of video and a hundred pictures taken. Also, we expended 100 hours of video editing, 30 hours of graphics creation, 40 hours of audio creation and 20 hours of format editing. We did not include overnight computations and processing.

We also did not address the issue of teamwork. It took days for us to coordinate our efforts with regard to uploading new versions to the net, and then accessing it for new audio or video editing. It then took more time for the originator to get the new material or feedback in order to use it for the next version.

Another pitfall is equipment and software. We started with one computer and Adobe™, but another computer was bought to speed the processing up. This can be a never-ending game of system maintenance.

A suggestion for interested parties would be to try to make a short (less than one minute) video as a trial for the process. Checking to make sure the system is in place can reveal significant issues may preclude show-stopping problems.

Assessment: Video vs. Education

The video itself can be assessed, and many rubrics already exist for this purpose. One that stood out was from Joan Vandervelde at UW Stout (8). These rubrics tend to address both the video content and video production qualities.

For our purposes, we chose to concentrate assessment on the educational impact of the videos. The feedback we sought on the video itself came from student surveys and their comments.

Education Assessment

The class formats for both MET345 and MET257 are 3-hour blocks, two days a week (6 quarter contact hours). Typical pedagogy includes a series of activities such as lecture/demo/lecture/activity scenarios. We were able to administer a survey for students that addressed their response to the video material.

Fielding pedagogical assessment is scheduled for spring quarter in 2010. A metric was desired that could compare new pedagogy with old (e.g. with last year's efforts). Also, it would be interesting to compare the effect of the video vs. demos or other activities. An example of a metric assessing the preparation of green sand is offered in Appendix A. This metric includes basic 'time-on-task' methodology, and is intended to evaluate the 'effectiveness' of using these videos.

A disclaimer of what we did not intend to accomplish is appropriate. The short time period precludes validation and longitudinal assessment aspects. Simple correlation was sought for an initial feedback. This applies to both the student surveys and our in-class assessments.

Results

Three casting videos were used in the fall, 2009, Production Technology course. The longer (20 minute) introductory video was shown first. During the same course period (3-hour block) the other two videos were shown as the topics appeared in the lecture. A demo in the foundry was performed after the lecture/video sequence. The following class period had students performing a casting operation for usable parts.

Instructor feedback from the fall 345 course was recorded. For comparison, similar amounts of time were spent (between the previous year and current, both taught by Mr. William Cattin) on the foundry introduction portion of the curricula. There were four lecture segments, three videos and one demonstration. The first lecture segment (introduction to casting processes) was the same for both years. Then the three videos were followed by their appropriate subject discussions (1^{st} video on process with safety, 2^{nd} video on sand management, and the 3^{rd} video on molding). There was no difference noted in the length of discussions related to each discussion, and no difference noted in the amount or quality of questions. There was also no difference in the amount of quality of questions during the demonstration. However, during the following class period students made significant references to the video (e.g. as they were trying to process the sand). As an indicator of the effectiveness of the videos, both the amount and quality of questions and discussion increased during this time.

Student surveys were completed by seven individuals (they did most of the foundry work in the 345 class). The survey only addressed the 'sand preparation' video. The results follow:

Sample: 7 students
1. How many times did you watch the video(s)? 1 (86%) 2 (0%) 3 (14%)
2. Did you watch the video outside of class hours? Y (71%), N (29%)

3. Did you have foundry experience before watching the videos? Y (100%)
4. Was the video helpful in understanding the foundry process? Y (100%)

Student comments included some on their impression of the video itself and its length: "shorten the video", "the video was a good length", and "the video was great". On the video audio: "jazz up the audio", "narration needs to be much more upbeat", and "have the dialogue scripted". On the animation and motion: "watch the whole job in fast motion", and "speed up the animation". On the content: "it showed how green sand works", "it show what green sand is", "very useful and informative", "maybe showing a finish product after risers and sprues have all been removed".

Discussion

The initial results were encouraging, in that some students both made reference to the videos in class, and accessed them off-line. The effectiveness of using of the videos during lecture was not as obvious to the instructor. It is easy to consider using the videos in this more traditional fashion, but not as easy to assess its worth.

The student feedback was encouraging in that all the respondents thought it worthwhile. Student comments were ambiguous regarding video length, but very positive with regard to content. The asynchronous access evidence supports further investigation. We plan to upload the videos to BlackBoard™ so that a quantitative feedback on 'asynchronous use' can be easily obtained.

To further investigate the effectiveness of the videos, we plan for two professors to teach two tracks of activity in MET257 during spring of 2010. Each professor will use the both the video vs. traditional as a control (for the sand management, for example), and then the professors will switch students and teach another content area (e.g. perhaps sand molding). A metric can then be applied to capture some feedback on educational effectiveness against a control. A plan is to digitally record the class, and then replay and analyze it for data on time-on-task (e.g. discussion lengths) and quality (level of questions and discussion).

Conclusion

The actual creation of quality video is quite expensive (both in time and money) due to production and editing issues. Though pitfalls can exist, high quality educational modules can be created.

Both students and instructor concur that the supplemental use of content specific videos enhances the education experience in our foundry courses. Though supported by observations and surveys, assessing the educational effectiveness is still problematic. A casting process metric was created for this purpose and is scheduled for use in our spring 2010 casting course.

Acknowledgements

Many thanks go to Mike Meier (www.KStreetStudio.com) for his generosity and skills. The videos may show CWU facilities and personnel, but they wouldn't have been created without Mike.

Thanks also to Bill Cattin and the students of MET345 for using the videos and providing feedback for this project.

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Appendix A: Casting Operations Metric on Green Sand Preparation

Casting Rubric: Preparing Green Sand

Objective: Measure the ability of a student to use the CWU Foundry equipment to prepare one wheelbarrow of green sand.

Resources: The evaluator will need to observe a student in the foundry.

Constraints: Available raw materials (sand, water, clay content, equipment) are required.

Metric assessing content:

	100%	50%	0	Score:
Safety	Wears appropriate PPE	Some PPE missing	Disregard for safety.	
Product Quality	Useable green sand	Poor quality sand	Unusable sand	
Use of Equipment	Equipment used and left in good condition.	Equipment needed attention after student used it.	Disrespect displayed for equipment.	
Quality of work	Student performed the operation competently.	Student needed help in completing the task.	Student workmanship is unacceptable.	

Metric assessing operation:

	Compare time to baseline (%)	Score:
Awareness Note: baseline time set.	Time to identify the equipment related to sand preparation.	
Plan Note: baseline time set.	Time for a dry-run of what the student plans to do in preparing the sand.	
Quality of work and ethics	Percent of time spent on the process (vs. distractions).	

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Sustainable Design: Meeting the Thunder Beings of the West

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Abstract

In the American West, sustaining the life support system for future generations implies acknowledgement that humanity is a part of the natural world rather than apart from it.[1-10] In this context, we are all related: the two-legged nations (men, birds), the four-leggeds, nations that spring from the ground, and those that live in the water. Even the rocks and stars are worthy of respect[11-20]. Education can play an important role in illuminating this integrated worldview by expanding our circle of understanding and action to include complex, self-organizing, interdependent systems, inspiring a sense of place through holistic, regional study, and introducing ourselves to the land.

Understanding the energy basis for man and nature[21-24] is equally fundamental to sustainability in the wild, rapidly changing American West since, over the long term, the biogeosphere must operate primarily on renewable solar, tidal, and deep earth energies. These bountiful energies manifest themselves in familiar ecological, economic, atmospheric, and hydro-geologic patterns on the earth's vast, biophysical stage. The evolutionary challenge for the West lies in sustaining the stocks and flows of energies necessary for constructing, heating, cooling, and maintaining the built environment; transporting people, goods, services, and information; establishing agricultural systems based on perennial crops and minimal toxins; regenerating land and waterscapes; reducing greenhouse gas emissions and capturing excess carbon; recycling materials, providing intellectually stimulating work for future generations, maintaining an acceptable standard of living, and caring for all.

A cultural metamorphosis comparable to the Enlightenment will be necessary to realize such a symbiosis[25-27]. The courage, wisdom, generosity, and fortitude to effect this vision, one in which all species live within the Earth's carrying capacity, may arise naturally or it may be forced upon us. Black Elk, the Ogallala Sioux holy man and noted Westerner[28] said, "When a vision comes from the thunder beings of the West, it comes with terror like a thunder storm; but when the storm of vision has passed, the world is greener and happier." This article presents initial efforts by students, staff, and faculty at Southern Utah University (SUU) to envision, design and build small-to-medium scale, regionally focused, sustainable systems, and share their results widely.

Sustainable Design at Southern Utah University

The Integrated Engineering Program at Southern Utah University (SUU) centers on an ABET-accredited curriculum, small classes, and regular student interaction with faculty and staff. Graduates are broadly educated, general engineers well versed in theory, having practical, hands-on experience, and well qualified to enter industry or engage in graduate study. The curriculum includes general education, science, mathematics, and engineering courses covering electrical, mechanical, and civil engineering topics.

In their junior year, students begin a two-year design sequence intended to integrate previous coursework and enhance professional communication skills. The first two courses, ENGR 3045 Engineering Design Lab I and ENGR 3095 Engineering Design Lab II, focus on systems thinking, case studies, effective communication, new technologies, project management, and small-to-medium scale, group-focused design projects which are reviewed, simulated, built, tested, documented, and presented in class. The senior year design courses ENGR 4025 Integrated Engineering Design Lab I, and ENGR 4085 Integrated Engineering Design Lab II focus on student-defined medium to large-scale design projects, which may involve cooperation with industry. Projects are presented to members of the university community and evaluated by faculty and industrial representatives.

During the last half of the Fall Semester, 2008, logistical considerations required a change in leadership and content of the two-semester junior design sequence. Sustainable design evolved as the primary focus. Improvements also included the addition of system-oriented topics, such as hierarchical vs. distributed systems, top-down vs. bottom up vs. integrative design, tools and methodologies for managing complexity, the maximum power principle[29], the pulsing paradigm[30], ecological engineering[31-34], and design considerations in a rapidly urbanizing world[35-36]. Previously, students engaged in the design sequence sometimes focused their efforts narrowly on a single level of the design hierarchy within the confines of a single discipline. Sustainability requires a broader sweep; one in which traditional engineering design processes are integrated with the myriad, complex interactions among energy, materials, information, economics, ecology, history, culture, esthetics, and politics, often across several scales. Following the decision to revise the junior sequence to focus on sustainable design, the question became what, precisely, to do in the junior design course given the limited time remaining.

Energy system diagramming, an integrative, visual framework borrowed from systems ecology provided a starting point for conversations about sustainable design. First employed by systems ecologist H.T. Odum[37-38], energy system diagrams illustrate the connections or functional relationships among system elements, and the stocks (storages) and flows of energies and materials within a system, including thermodynamic losses. A representative diagram[39] is provided in Figure 1, with the system boundary chosen (dark line) enclosing a generalized city and support region. Water tank-shaped symbols are storages (state variables); lines represent flows (derivatives of state variables); circles are energy, material, or information sources; bullet-shaped symbols and hexagons are production and consumption elements; arrows are interactions (additions, multiplications, etc.); diamonds illustrate exchanges of money for products, services, or information; the ground symbol is a sink for second-law and other system losses; and rectangles are aggregations of other elements. In Figure 1, for example, it can be seen that the production element labeled “Agriculture” receives renewable and non-renewable energies, materials, money, goods, and services fed back from the rectangle representing commerce & industry, plus waste. Wild, “Natural Ecosystems” receive renewable energies, plus waste in various forms, but no money. “Commerce and Industry” receive inputs from several sources, directly and indirectly, and output goods and services to people and markets. Quantitative values for these variables are often included in the diagrams, which are then readily translated to mathematical models suitable for computer simulation[40].

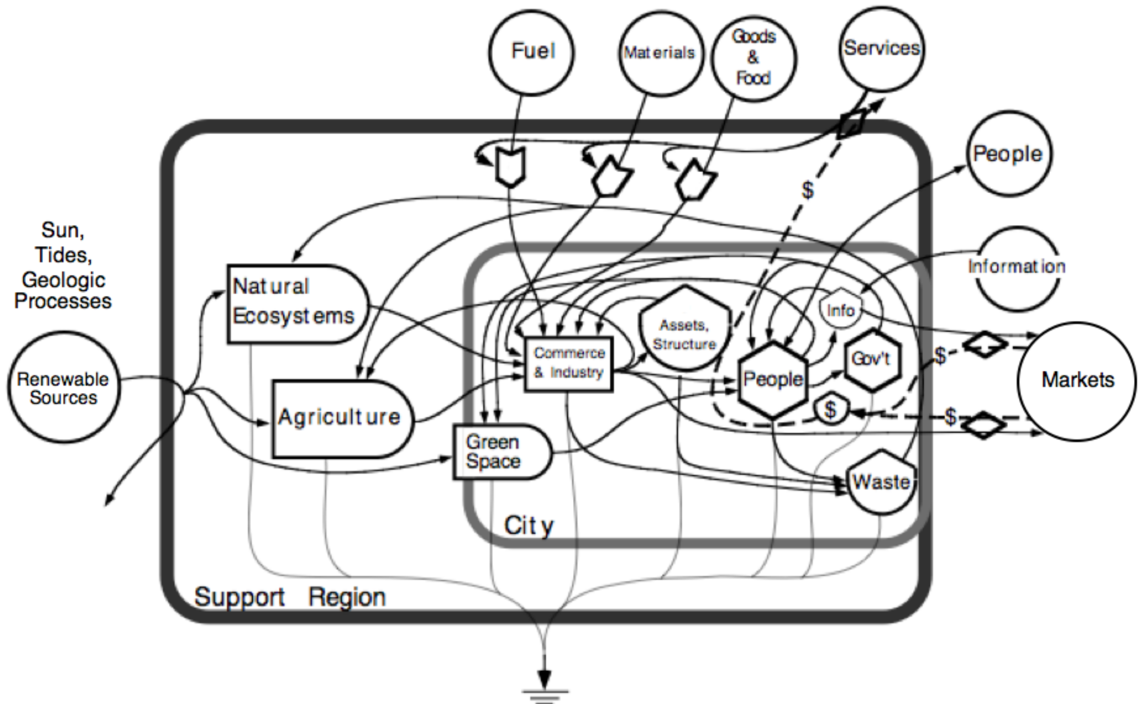

Figure 1. Sustainable System Design Framework, Regional Scale

System boundaries were expanded as the course progressed, with the resulting systems considered at national, continental, and biospheric scales. At these higher levels in the system hierarchy, many blocks are aggregated into a few having the same net behavioral properties. System boundaries were also reduced to the local and community levels, with the associated subsystems examined in greater detail. For example, we considered the sustainability of passive solar homes designed explicitly for the Southwest as community level subsystems located within the storage element labeled, "Assets and Structures" in Figure 1. The abundant solar energy available for heating and cooling homes in Cedar City, Utah, for example, averages 3.9 $kWh/m^2/day$ on south-facing vertical surfaces[41] such as windows. Irradiation on surfaces tilted from the horizontal at an angle equal to the city's latitude averages 5.9 $kWh/m^2/day$. Surfaces tilted in this manner are optimal for solar photovoltaic systems and hot water production[42-43]. The city's elevation, 5844 feet, moderates the effect of otherwise hot Western summers, allowing photovoltaic systems to operate more efficiently than in other locations at the same latitude. In addition, net metering of on-grid photovoltaic systems is encouraged regionally. Federal and state tax credits and utility-based incentives also exist.

The long-term sustainability implications of passive solar home design in the region became readily apparent after considering three energy efficient home designs[44-46] from the National Renewable Energy Laboratory, conversations with a spectrum of architects and engineers, discussions with a local solar design and installation firm, and calculations that indicated the costs of creating, operating, and maintaining new homes operated largely on solar energy with extensive insulation, energy efficient appliances, water capture, storage, and reuse systems, and ecologically appropriate landscaping may be significantly less, over the long term, than fossil fuel driven, traditionally constructed homes. This realization catalyzed exciting discussions within the junior design class at SUU, encompassing a range of topics at several scales, including passive vs. active system designs, potential fossil fuel reductions resulting from large-scale introduction of solar-powered, zero-energy buildings, tradeoffs between individual roof or yard mounted solar systems and community-scale designs, quality of life and regional population growth, suitable backup heating systems, equity issues surrounding the cost of retrofitting existing homes and offices with green technologies, the embodied energies or "emergy" associated with fabricating photovoltaic cells and solar hot water systems, the relationship between carbon emissions, electric cars, and smart-grids, systemic and individual solar costs and benefits, government and utility-based incentives, sources for and recycling of rare-earth solar cell components, non-toxic materials, integrated simulation environments, aquifer recharge issues in the face of increasing, potentially impermeable solar-covered surfaces, evolving a well-educated solar workforce, prefabricated construction systems (building compilers), affordable, long-lived, esthetically pleasing dwellings, and the detailed, technical design aspects of individual solar homes. In the Pacific Northwest, it was suggested, class discussions might center on mechanisms for tidal energy generation. In Minnesota, parts of the American West, and some coastal regions, wind generation might be more appropriate. It was concluded that thinking about systems holistically, at multiple levels of abstraction, across several scales of space and time, using visually oriented energy system diagrams and integrative simulation environments may result in better designs and the opportunity for improved lives.

Adventures in Sustainability

Forcefully limiting the scope of our work in the Fall of 2008 to sustainability in the context of the built environment, including land and waterscapes, was the second step forward in improving the junior design course[47-58]. It was decided that the class would design, simulate, implement, and test several 1/24th-scale passive solar home prototypes (functional models) during the five weeks remaining in the semester. This decision was motivated by regional energy, climate, economic, ecological, and demographic considerations[59-63], including rising fossil fuel prices, visibly apparent climate change, an extended downturn in the building sector, water scarcity due to continuing drought, and a growing population. Providing students with the opportunity to participate in design adventures[64] motivated by regional events appeared to be an idea whose time had come.

The first sustainable designs to be completed by students in the Fall of 2008 were 1/24-Scale passive solar home prototypes. One of many implementations is shown in Figure 2. The passive solar home prototypes incorporated water for solar energy storage (thermal mass). Fifteen to thirty 14-ounce cans of water, painted dull black, with corks inserted for safety, were used for this purpose. During the day, short-wavelength solar radiation passing through the glass windows, such as the foam-enclosed window shown on the left in Figure 2, was transformed into heat in the blackened, energy absorbing, metal cans, and the energy transferred to the water, resulting in increased water and air temperatures. The lower-wavelength thermal energy of the water was largely "trapped" by the windows (greenhouse effect). Elevated interior temperatures were maintained for extended periods due to the high specific heat of the water. Energy was

Figure 2. ENGR 3045 Engineering Design Lab I, "Junior Design I," Fall 2008,
Passive Solar Home (1/24-Scale), Thermal Mass (Water), Window, Data Acquisition System

gradually lost at night by conduction through the insulating walls and high thermal conductance front windows (unless covered by insulation) with a resulting decrease in interior temperature. Masonry was not used for thermal storage due to the limited interior space and its lower specific heat, although masonry may be used in more spacious, future designs. Laptop computers running National Instruments' Labview Software, NI USB 6009 Data Acquisition Systems, and two National Semiconductor LM34 temperature sensors per system were used to record temperatures inside and outside the homes. Passive solar design strategies from Mazria's "The Passive Solar Energy Book[65]," Duffie & Beckman's "Solar Engineering of Thermal Processes[66]," Brown & DeKay's, "Sun Wind, and Light: Architectural Design Strategies.[67], " Wright's "The Passive Solar Primer: Sustainable Architecture[68]," and Tabb's "Solar Energy Planning[69]," were used in the design process. The initial solar prototypes were designed, simulated, constructed, and tested in the field in five weeks. Coleman 48 Quart Chest Coolers were used to implement the homes, with their glass-covered, open, insulated tops oriented toward the south. A custom-made solar prototype was also constructed using 1-1/2" slabs of expanded polystyrene insulation (R-7.5) known commercially as "blue board" (painted white to reflect light within the home toward the cans of water), and double pane, 1/8 inch glass for the 1 ft^2 south-facing, vertical window. The dimensions of the custom prototype were 19" W x 12" H x 13.5" D. At sunset, the lids of the coolers were closed to reduce thermal losses through the glass. In the case of the polystyrene prototype, a foam window cover was created and held in place with backpacking straps. Covers were removed at sunrise to allow light to enter.

System Simulation & Field Measurements

Simulink simulations of the 2008 homes were performed using models based on thermal conductance or U-values (U = 1/Thermal Resistance) calculated using geometries of the walls and windows, solar gains calculated using the National Renewable Energy Laboratory's Solar Radiation Data Manual for Buildings in conjunction with measured horizontal surface irradiance data from the Weather Underground Web Site (Cedar City), and the calculated thermal mass of each system. Solar radiation data used in the simulations was specified for a particular month (e.g. November), and allowed to vary uniformly each day within the month. Cloud cover and humidity effects were not included. Performance in the field matched the simulations closely.

In the Fall of 2009, Engineering Design Lab I was offered once again. The new junior design teams improved on the previous data acquisition systems and implemented several innovative designs, including a prototype home incorporating a horizontally-oriented glass floor which received light from a mirror tilted at the proper angle to project light through the floor into a thermal storage system consisting of a pool of water lined with black, absorbent material, over which potential occupants lived.

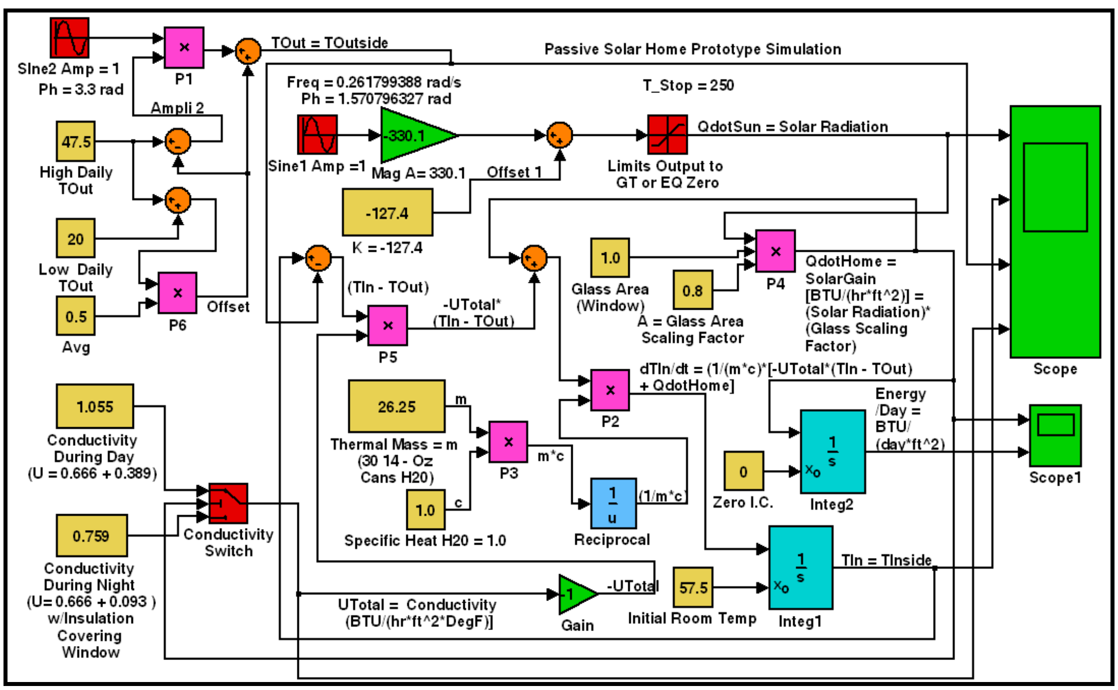

Figure 3. Passive Solar Home (1/24-Scale) Simulink Simulation, November 2009

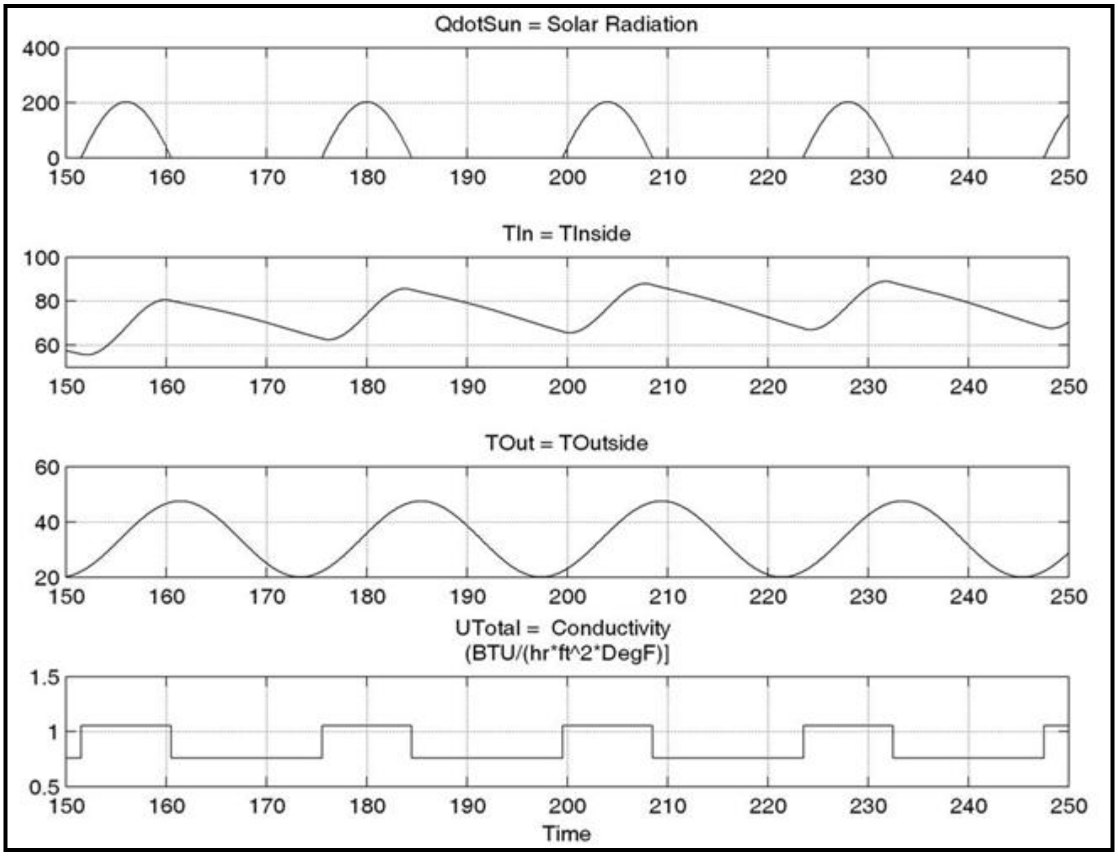

Figure 4. Passive Solar Home Simulink Simulation Output, November 2009

The results of the 2009 system simulations are shown in Figures 3 and 4. Following simulation, students proceeded with construction, and the new systems were soon deployed in the field for testing. Results from a four-day field test conducted in November 2009 are presented in Figure 5, including temperatures inside and outside the home plus horizontal surface irradiation. Note that the temperature within the home during the first night approached 58 ˚F due to several days of cold, cloudy weather preceding the test. The average inside (interior) temperature gradually increased over the next several days due to clear skies and intense sunlight. During the last day, the temperature within the home varied from 62˚F to 84 ˚F, a 22˚F difference. Interior temperature increased slightly following the test due to continued sunlight during daylight hours. To decrease inside temperature variations to a more comfortable 15˚F, a shading device was added following the test to allow the window to be partially covered, blocking incoming sunlight, as needed. Anticipation of such shading based on weather forecasts improved system performance in the absence of significantly greater thermal mass. Field measurements generally matched simulation results within 10-20% when the solar irradiation inputs to the simulation were modified to more closely reflect actual field conditions. Solar radiation data from a recently acquired Eppley Labs B&W Pyranometer, Model 8-48 should increase simulation accuracy.

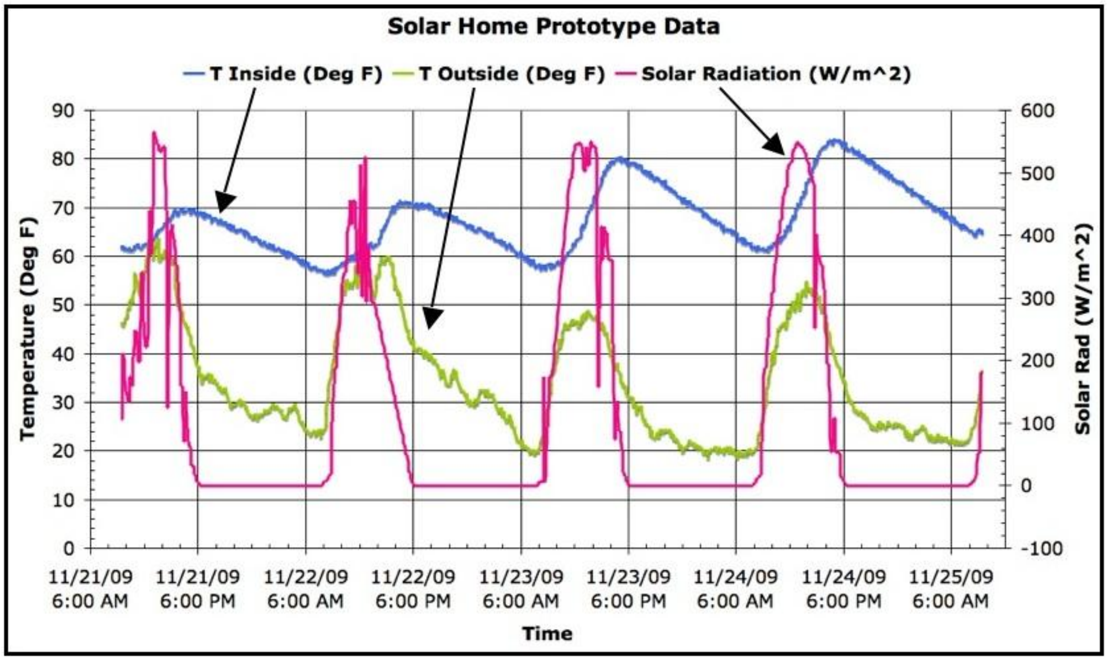

Figure 5. Passive Solar Home (1/24-Scale) Prototype Irradiance and Temperature Data

Engineering in the 21st Century

An introductory engineering course, ENGR 1010 "Engineering in the 21st Century," was also offered in the Fall of 2009. Enrollment included freshmen from several disciplines and engineering majors completing their general education requirements. Since no prerequisites existed for the course, we employed a constructivist learning strategy referred to as "Just-In-Time-Theory," which starts from where the students are, and assists them in learning, step-by-step, in a team context, what's necessary to design, dynamically simulate, build, and test small-scale systems, e.g. a plastic milk-jug-based watershed model. Fundamental ideas from the Calculus, carefully orchestrated Excel and Simulink simulation tutorials, and selected case studies made this possible. Over time, elements of sustainable design and energy system thinking related to the built environment have been added to the course.

Student interest in the built environment developed rapidly after viewing a video of architect William McDonough's efforts at Oberlin College, designing a minimally toxic, recyclable carpet manufacturing system, with Ford Motor Company at River Rouge, and in China. Further inspiration was provided by slides showing SUU undergraduate and University of Utah graduate student activities during a 2008 expedition to assist with DesignBuildBLUFF[70-71], a project led by architecture professor Hank Lewis. Modeled after Samuel Mockbee's work[72] at Auburn University's Rural Studio, the project provides innovative, energy-efficient, pro bono homes for selected Navajo families living on the reservation near Bluff, Utah. Following a subsequent presentation on SUU's entry into the competition for Solar Decathlon funding, and the possibility of direct involvement, the freshmen (and women) expressed an interest in building a small-scale prototype solar home. When asked about their intent, many students said they wanted to create an energy efficient, affordable, attractive, sturdy home for a small family. In order to stimulate architectural thinking, they were exposed to a range of home designs and the expressed intent of the designers, including works by Frank Lloyd Wright, Buckminster Fuller, and contemporary solar architects employing a spectrum of building styles and materials. They were also made aware of junior designs previously completed. They were then asked to complete a design of their own choosing for a 1000 ft^2 passive solar home, providing freehand or computer-based sketches, elevations, and floor plans as deliverables. An example floor plan is shown in Figure 6. In this case, orienting the rectangular home on the building site with its long axis running east and west presented an opportunity for maximizing solar gain. Architectural theories regarding space and flow suggested partitioning the long, compact home into energy and light, living, circulation, and service spaces. Solar energy arriving through south-facing windows is stored in water walls where it radiates into the rest of the house. The water walls, transparent at the top and black elsewhere, also contain wetland plants capable of cleaning greywater produced in the home. An experiment to introduce Tilapia into the water walls as a protein source is also under consideration. Northward, an open kitchen, bedrooms, and a living/dining area constitute the living space. A hallway connects the living space to the service space consisting of a bathroom, utility area, workspace, storage areas, and a woodstove for backup heating located adjacent to the north wall. Clerestory windows, solar tubes for interior illumination, photovoltaic panels, a solar hot water system, an on demand water heater, and a rain-capturing roof and cistern are included in the design, but not illustrated.

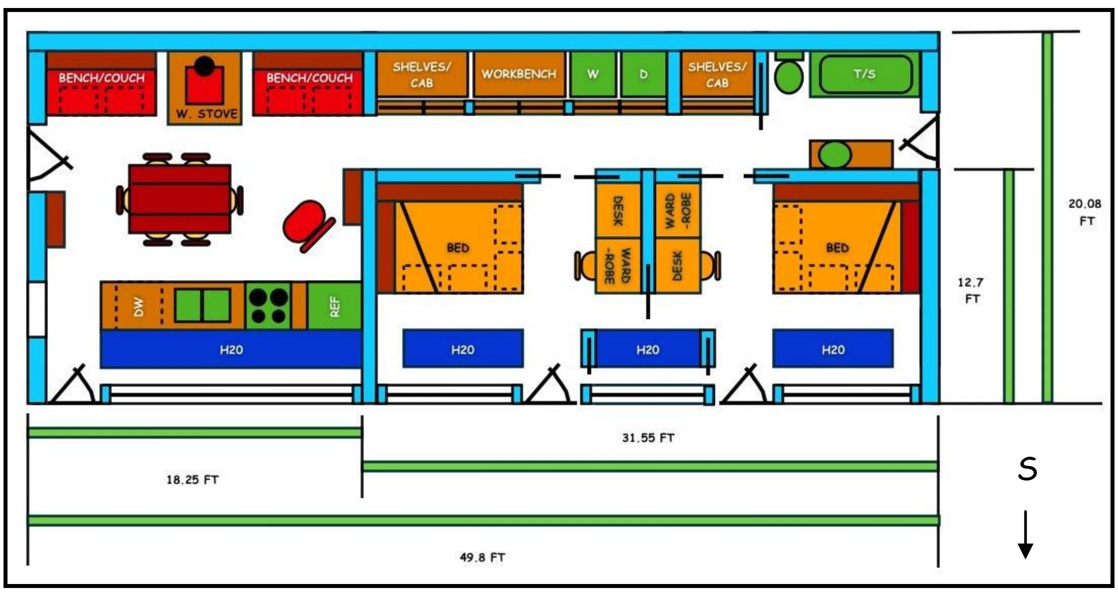

Figure 6. ENGR 1010 "Engineering in the 21st Century" Example Solar Home Floor Plan

The class of thirty-three students was subsequently partitioned in half, assigned to form self-directed teams, and asked to design and build two esthetically pleasing, 1/12-scale, functional solar home prototypes in three weeks. The homes, shown in Figure 7, include R-7.5 "blueboard" insulated walls, south-facing windows and clerestories made of plexiglass, tan stucco exteriors, white interiors, and green metal (commercial) roofing systems. Chicken broth (primarily water) was used for thermal mass. The project was completed the last day of exam week, Fall 2009.

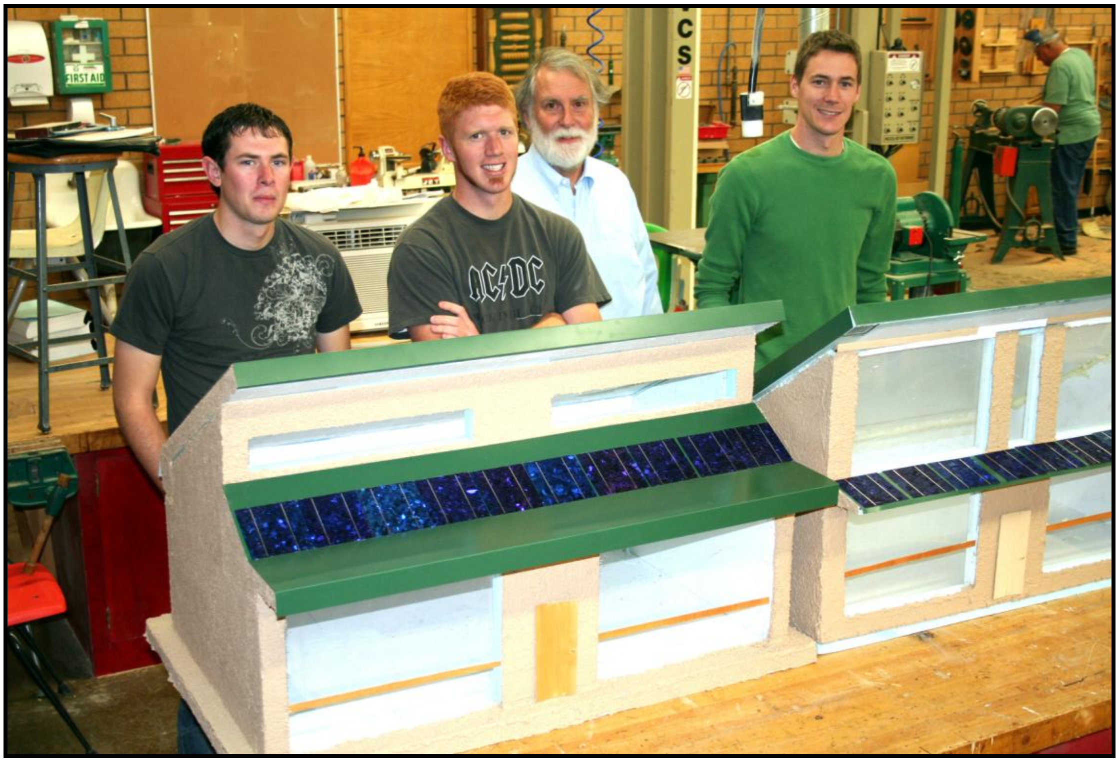

Figure 7. Freshmen Students, Professor, ENGR 1010 “Engineering in the 21st Century” Passive Solar Home Projects (1/12-Scale), & Photovoltaic Panels. Thermal Mass Not Shown

Temperature sensors, data acquisition systems, and solar PV systems are currently being installed, with field-testing to follow. Class assessment tool development is also underway.

Conclusions

The thunderous pronouncements of Black Elk may soon take form in the designs of visionary students motivated to create a sustainable life for themselves and those who follow. Full-scale solar home designs, implemented using Revit Architecture software, have been started. It is our intent to employ prefabricated structural element models in Revit as they become available to accelerate project completion, and to use Revit and associated CAD tools to perform a complete thermal, lighting, structural, and economic analysis of each design.

A team including students, staff, and faculty from the engineering and construction management programs has also entered the competition for Solar Decathlon funding, partly as a result of what was learned through the explorations presented in this article. Additional work in quantitatively assessing the sustainability of Utah using energy system-based accounting techniques, in conjunction with the USEPA, remains to be completed.

A role we hope to play on a larger landscape is reflected in a quote from historian James Ronda’s book, Lewis and Clark Among the Indians[73]: “The expedition was a diverse human community moving through the lands and lives of other communities...This larger Corps of Discovery is a reminder that we are all pilgrims on the way, making our way by the kindness of strangers.”

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Curricular Innovation for Real-Time Embedded Systems Course

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Abstract

The objective of this project is to experience and develop rapid prototypes of System-on-chip (SoC) using soft-core processor in the undergraduate laboratory. We will share the experience on a reconfigurable hardware-software co-design environment and µClinux embedded Real Time Operating System (RTOS). A soft core processor is a microcontroller developed in software, which can be synthesized in a FPGA. A soft-core processor approach is ideal for teaching the embedded systems design course in electrical and computer engineering majors. It allows students to customize the exact set of several CPU's peripherals and the interfaces needed for scientific application. The ultimate goal is to disseminate the soft-core processor experience for teaching and learning in the department and enabling students enough flexibility to configure a processor according to their design project needs. The lesson learned from this experience is valued and a new embedded systems design course has been developed in our department.

Introduction

Any device that includes a programmable computer but is not itself a general-purpose computer is termed as an embedded system. It is a special purpose computer which is designed to do certain dedicated functions. FPGA-based embedded system using soft-core processors are adapted more commercially and gained popularity in university teaching. Hence, we are motivated to practice a new pedagogy in learning embedded system where students will have the option of customizing their own peripheral subsystem. Along with this pedagogy we have integrated the µClinux, a Real Time Operating System (RTOS) into classroom/laboratory experience for students to learn embedded systems[1]. Embedded systems are preferred over general computers because of the following advantages:

1. Real-time operation
2. Low manufacturing cost
3. Reliability and security

In general embedded systems are not recognizable as regular computers. Embedded systems typically do not interface with the outside world through familiar personal computer interface devices such as mouse, keyboard and graphic user interfaces. Instead, they interface with the outside world through unusual interfaces such as sensors and other communication links. Most time-constrained resource allocations and task scheduling across spectrum of subsystems such as sensor and actuators processing, communications, CPU, memory and other peripheral devices today are required to use RTOS in order to meet the system response. The practical details of implementing and integrating a RTOS with a soft core processor for interfacing real-time services and data processing through different I/O subsystems are the focus of this paper. Embedded systems are implemented using the following classification of processors:

1. Hard- core processors
2. Soft-core processors

The hard-core processor consumes more power than the soft-core processors and is not flexible. They are also big in size and the possibility of losing hardware connections is higher in hard-core processors. Hard core processors are fast but when we need more data processing, like mathematical operations, data arrays, data sorting, or anything that does not need a quick result we can use soft core processors. Above all, a soft core processor targeting FPGA is flexible because its parameters can be changed at any time by reprogramming the device. [2] There are many different kinds of soft-core processors available in market now days. Some of them are –

1. ARM
2. Xilinx
3. Zylin AS
4. NIOS II

The Altera's NIOS II is available in the Electrical Engineering Department. So we will be concentrating on the NIOS II processor.

NIOS II System

NIOS embedded processors were introduced in 2001 in the electronics industry by Altera as the viable commercial processor specially created for embedded system design in FPGAs. Since then it has been used widely in the industry. It is a 32 bit soft-core processor, which is defined in a hardware descriptive language. It can be implemented in Altera's FPGA devices (DE2) by using the Quartus II CAD system. The soft-core nature of the NIOS II processor lets the system designer specify and generate a custom NIOS II core, tailored for his specific application requirements. [3]

NIOS II processors allow us to-

1. Customize the CPUs, peripherals and the interfaces needed for aforementioned application.
2. Increase performance by implementing Real-time embedded system applications.
3. Lower laboratory cost by not spending additional money on hardware microcontroller board.

The NIOS II processor can be used with a variety of other components to form a omplete system. Altera's DE2 Development and educational board contain several components that can be integrated into a NIOS II system. An example of such system is shown in figure 1. The NIOS II processor has Reduced Instruction Set Computer (RISC) architecture. Its arithmetic and logic operations are performed on operands in the general purpose registers. The data is moved between the memory and these registers by means of Load and Store instructions. The word length of the NIOS II processor is 32 bits. All registers are 32 bits long. The NIOS II architecture uses separate instruction and data buses, which is often referred to as the *Harvard* architecture. [4]

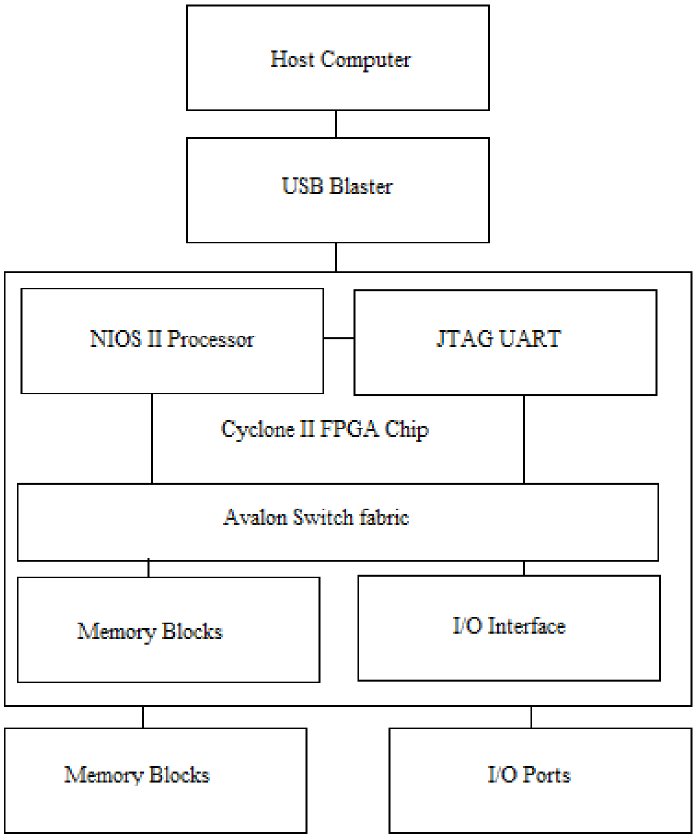

Figure 1-Nios II system implemented on the DE2 board

µClinux

Real-time and embedded systems operate in constrained environments in which computer memory and processing power are limited. They often need to provide their services within strict time deadlines to their users and to the surrounding world. It is these memory, speed and timing constraints that dictate the use of real-time operating systems in embedded software. RTOS kernels hide from application software to the low-level details of system hardware, and at the same time provide several categories of services to theapplication software. These include: task management with priority-based preemptive scheduling, reliable inter task communication and synchronization, non-fragmenting dynamic memory allocation, and basic timer services. [10] The µClinux kernel supports multiple of different CPU platform including Altera's NIOS II architecture. The main advantage of this OS is that it is an open source project and it is smaller than the regular Linux kernels. Most features of Linux kernel are available, like process control, file system, networking, and device drivers. [6]

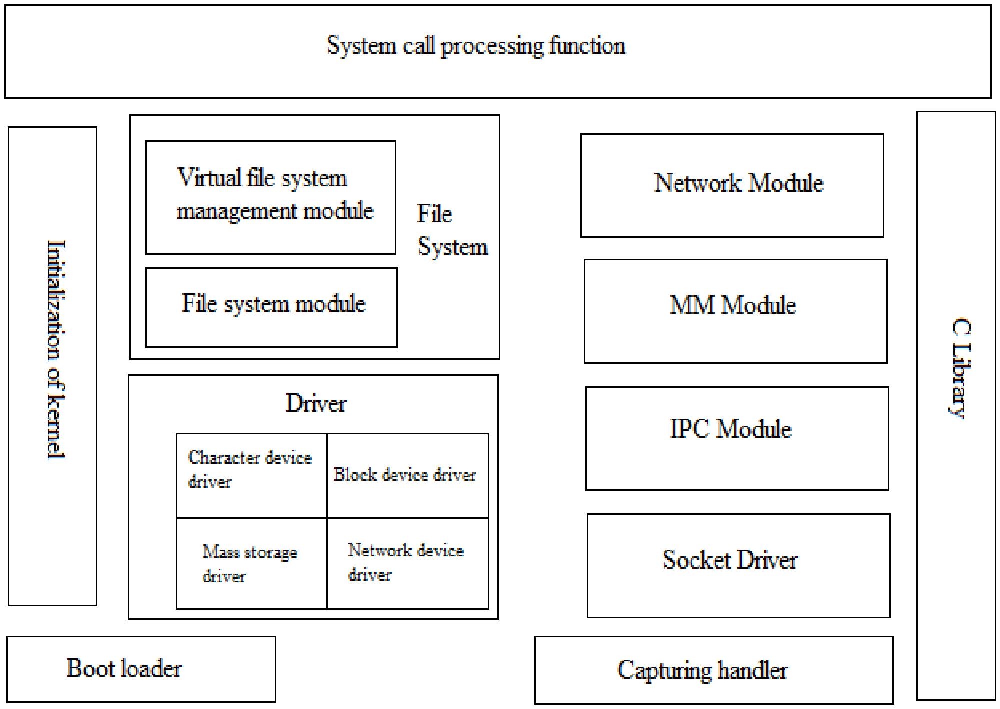

Figure 2- Architecture of µClinux [7]

µClinux Implementation on Soft-Core Processor

Altera's DE2 board is shown in Figure 3. We will use this board as a vehicle for teaching and learning the new embedded systems course. Students will experiment the design and implementation of RTOS using NIOS II soft-core processor that supports flexible memory option and I/O device combination. Design project to deal with real-time task using interrupt programming, connections with I/O devices such as audio, video, USB, network and memory are examples of experiments that are implemented.

NIOS II Integrated Development Environment (IDE) is the standalone program that helps us to accomplish our task of implementing µClinux over the FPGA device. NIOS II IDE 9.0 is the latest version of the software and can be downloaded from the Altera website. The distribution for µClinux can be obtained from http://nioswiki.jot.com/WikiHome/. The Nios community develops and releases the latest kernels according to Altera software release. Because of the licensing issue we have build the uClinux kernel in Linux environment and then transfer the kernel image into the windows to do the rest of our project. Running the µClinux in DE2 board requires two steps. First the FPGA must be configured to implement the NIOS II processor system, and second the µClinux kernels image must be downloaded into SDRAM on the DE2 board. Both configuration steps can be accomplished via the NIOS II 9.0 command shell.

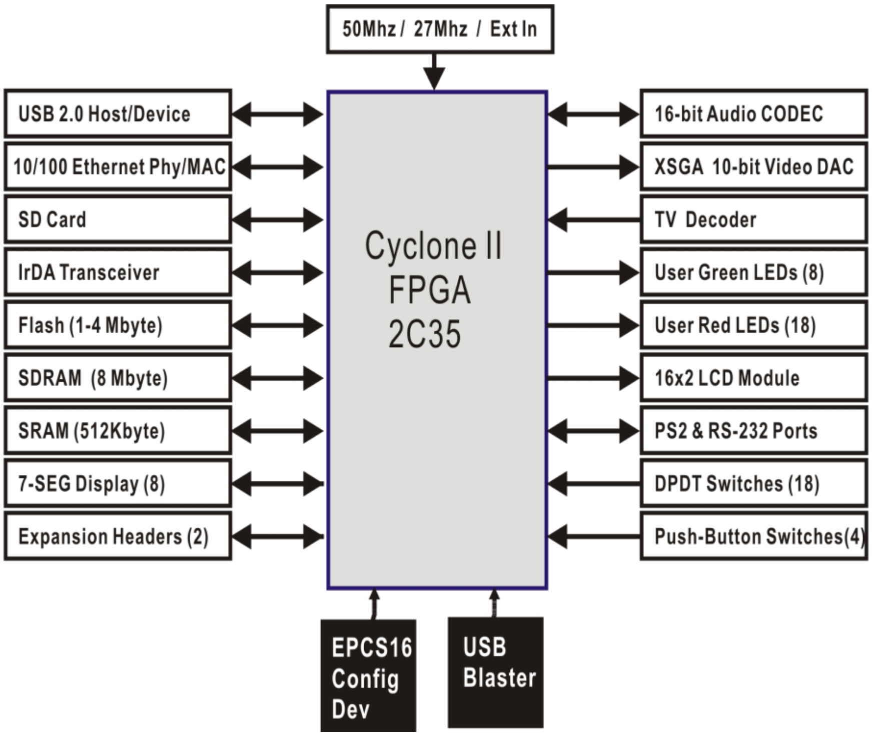

Figure3 -Altera DE board block diagram [2]

Before starting the configuration of the DE board the power cable should be well connected, the DE2 board should be turned ON and USB cable is connected between the PC and the USB blaster port on the DE board. We used an existing NIOS II project from the demonstrations directory of the enclosed DE2 CD-ROM. We have chosen DE2_NIOS_HOST_MOUSE_VGA project. We used *wget* command in Linux terminal to download the µClinux distribution. A basic µClinux kernel image is built uing the *make menuconfig* command. The built image is located on nios-linux/uClinux-dist/image/zimage. Zimage is nothing but a compressed form of a kernel image. The Linux kernel takes care of expanding the image at boot. On Linux systems, vmLinux is a statically linked executable file that contains the Linux kernel in one of the executable file formats supported by Linux, including ELF, COFF and a.out. To configure the FPGA and download the zImage to the processor we will write the following command steps in NIOS II 9.0 command shell.[5]

step 1. Configure the FPGA,
nios2-configure-sof DE2_NIOS_HOST_MOUSE_VGA.sof
step 2. Download and run the kernel image,
nios2-download -g zImage_DE2_NIOS_HOST_MOUSE_VGA_v1.6

After the kernel image is downloaded into the DE2 board, µClinux in *nios2-terminal* is active and ready as shown in Figure 4.

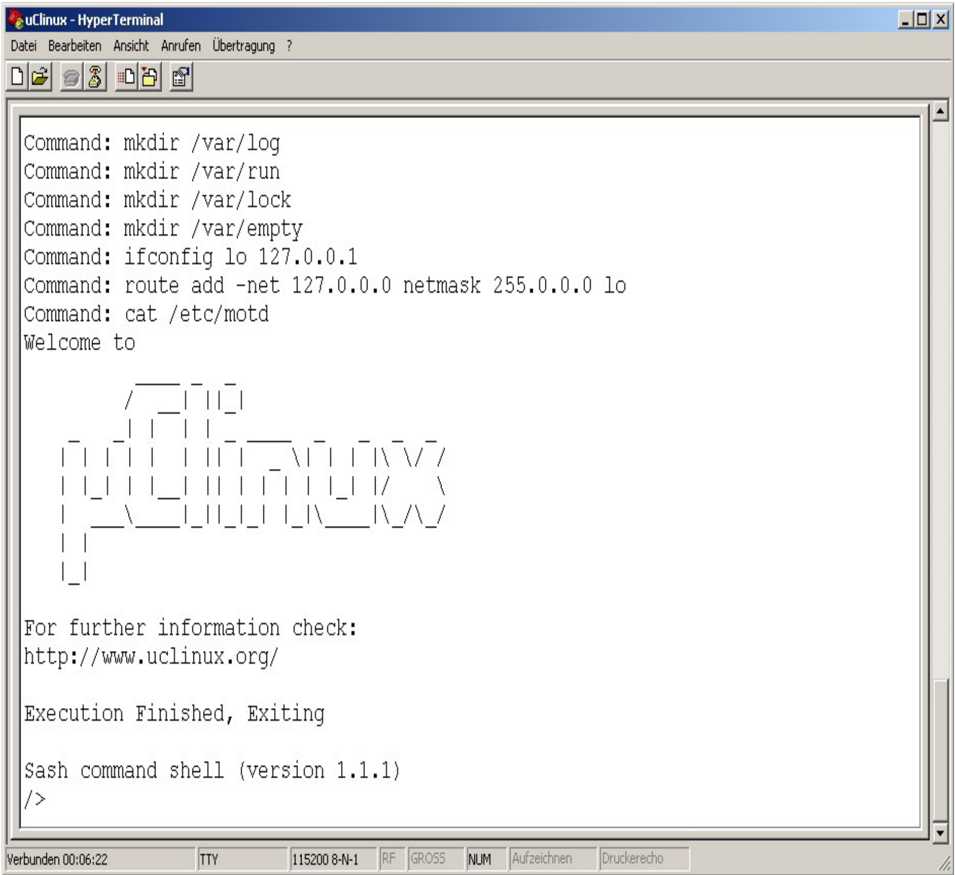

Figure 4- A basic uClinux kernel image

Application

The µClinux is configured on our NIOS II system and is ready for use. The next step is customizing kernel and adding a user application. We will log into Linux platform and will do the *make menuconfig*. One of the application experiments is to complete the Ethernet interfacing, and connecting our board to the outside world. This will be done by invoking ftp and telnet. We also activate the Ethernet network support while doing the *make menuconfig*.

To check the Ethernet connection we will run the *ifconfig* command. *ifconfig* command allows the operating system to setup network interfaces and allow the user to view information about the configured network interfaces. [6] If a valid IP address is displayed after the label *inet addr* as shown in figure 5, then the DE2 board is successfully communicating on the network.

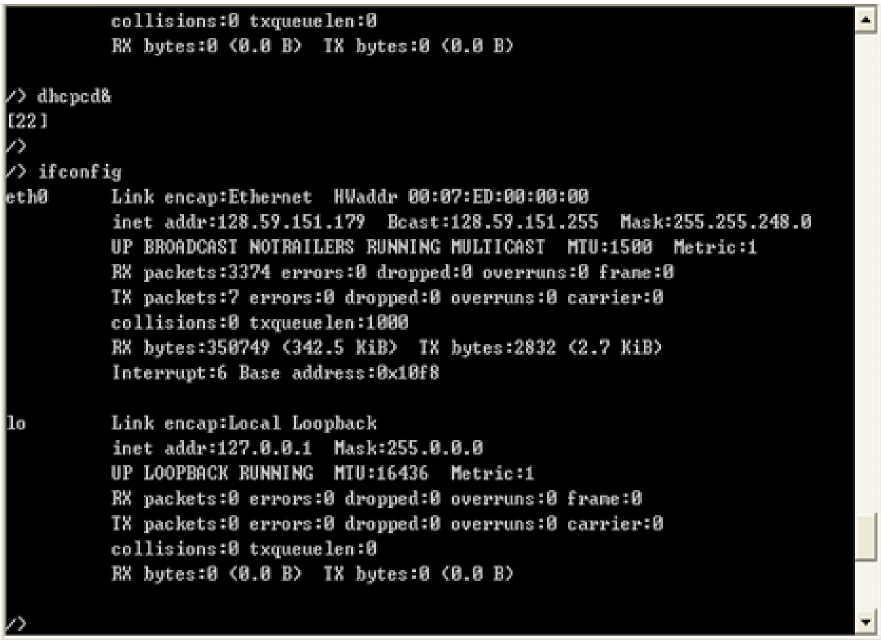

Figure 5- ifconfig result

Furthermore, the NIOS II processor developed system was used to implement variety of experiments. Examples are writing a device driver for the LCD controller interface and I/O and interrupt programming. Figure 6 shows an I/O interface waveform generation of a 70% duty cycle as displayed on an oscilloscope. This experiment was implemented using C Language.

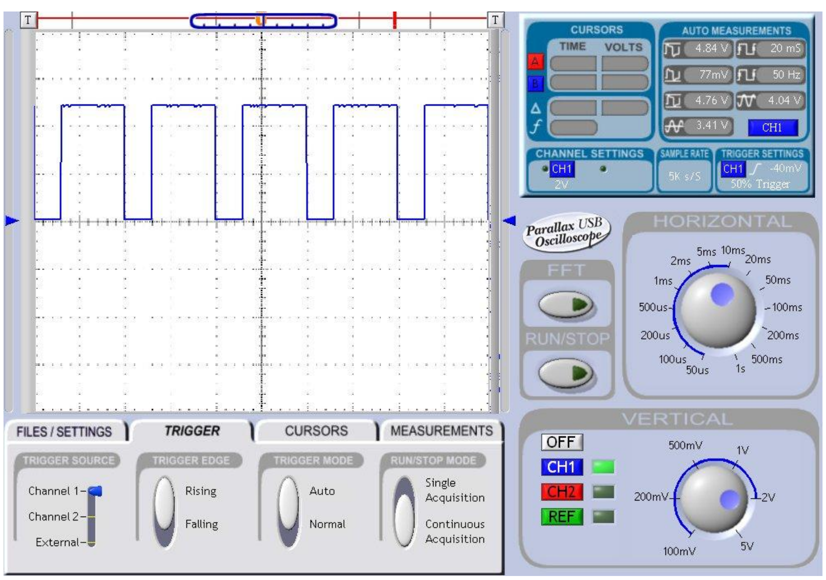

Figure 6- Output in oscilloscope

Conclusion

As a result of this project, a new course ECE 178, embedded systems, course has been developed. This course will demonstrate soft-core processor embedded system which will be implemented on a real time operating system over the FPGA's. During this project, we have also shown how to add applications in the Linux kernels. The Ethernet connection application and some other I/O and interrupt programming has been implemented. The scope of this project is very vast and we have set the platform now for teaching this new approach for learning embedded systems concepts.

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Work in Progress:
A Learning Community for First-Year Engineering Students

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Abstract

A learning community has been established for first-year students in the Department of Engineering at Colorado State University - Pueblo. Two engineering courses were linked by shared homework assignments and a robotics lab was added. A survey was developed and administered before and after the lab to evaluate students' satisfaction with the lab experience. Results show an improvement for all survey questions. Future work will assess students' performance and retention.

Background

It is well-known that the largest attrition in engineering programs in many institutions occurs during the first-year of study[1-4]. Many educators have discussed this problem and proposed various solutions. One of the prominent approaches is to build a learning community by linking courses[2, 3].

At CSU-Pueblo, a pilot learning community was initiated in the Department of Engineering. Two first-year courses were linked with shared homework assignments. In addition, a three-hour robotics lab was added to stimulate students' interest in engineering, to introduce students to team work, and to allow students to meet other faculty members in the program. These three items are known strategies for increasing retention.

Approach

The primary objective of the learning community at the CSU-Pueblo engineering department is to improve the retention of the first-year engineering students. A learning community has been established for two first-year engineering courses. The two courses, *Introduction to Engineering* and *Problem Solving for Engineers*, introduce programming concepts and two programming languages to the learning community of the first-year engineering students. While *Introduction to Engineering* is a broad-based preliminary course for all freshman students who are interested in engineering, *Problem Solving for Engineers* is a more specific MATLAB-based programming course. The learning community is established first by having joint homework/lab assignments in both MATLAB and Excel. These assignments consist of reading and manipulating data, applying formulas and then plotting the results.

Second, the *Introduction to Engineering* course has a lab in which each group of students builds and programs a LEGO Mindstorms NXT Robot to accomplish certain tasks by using the Mindstorms NXT graphical programming language. In the near future, in the *Problem Solving for Engineers* course, a joint assignment will be given to finish the same tasks by using MATLAB to help the students learn the differences between a text-based programming language like MATLAB and a graphical programming language like Mindstorms NXT. Furthermore, the robots built by the best team will be displayed in cabinets near the classroom along with the group pictures.

Third, there will be monthly meetings of the faculty to discuss the students' performance, class schedules and other related issues dealing with the learning community of first-year students.

Observations and Results

A survey was developed and administered before and after the robotics lab to evaluate students' satisfaction and the knowledge gained. The questions and the results are shown in Table 1 (1 being the lowest and 5 being the highest rating). Nineteen students took the pre-lab survey while 16 students took the post-lab survey. The average rating for all five questions improved. Since the learning community has been established for only one semester there is little data on grades and retention. At this time we have observed that students' performance has improved and the failure rate has decreased. This will be more thoroughly assessed in the future.

Table 1: Survey Results

Survey Questions	Average (before)	Average (after)
1. How excited are you about engineering?	3.58	4.13
2. How excited are you about robots?	3.89	4.19
3. How confident are you in designing robots with LEGOs?	3.37	4.38
4. How confident are you in programming robots to accomplish a given task?	2.95	3.94
5. How comfortable are you with working in a team?	4.21	4.44

Conclusion and Future Work

A learning community was created by linking homework assignments of two first-year engineering courses, and by introducing a robotics lab. The results show an improvement in students' satisfaction of the overall experience. The effect of the learning community on students' learning and retention will be assessed in the future. The students that are enrolled in only one of the classes will serve as a control group.

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Assessing the Effectiveness of Synchronous Content Delivery in an Online Introductory Circuits Analysis Course

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Abstract

A 2008 study released by the US Department of Education indicates that online enrollments are growing at substantially faster rates than overall higher education enrollments (12.9% vs. 1.2%), with over 3.9 million students (or over 20% of all U.S. higher education students) taking at least one online course in the fall of 2007. The study also reveals that among the eight major discipline areas examined, engineering has much lower online representation compared to others. One reason for this slow adoption of online teaching pedagogies in US engineering programs can be attributed to the perception by some engineering faculty and administrators that online courses are not equivalent in content and rigor when compared to the traditional, face-to-face courses. This paper presents the results of a study comparing the performance of on-campus and online students in a sophomore-level Circuits Analysis course in a public two-year institution. In this introductory course for all engineering majors, content is delivered simultaneously to on-campus students and online students (dual delivery mode) using a combination of Tablet PC functionality and Elluminate Live! software that allows synchronous delivery through the Internet, as well as recording and archiving of all classroom lecture sessions. Identical homework sets and tests were given to the two groups, and their performance compared. Results show that there is no statistically significant difference in the levels of performance of the two groups of students. Online students also rated their experience in this online class to be better than other online courses they have previously taken.

1. Introduction

Online teaching is one of the fastest growing trends in educational technology in the U.S. A 2008 study[1] released by the US Department of Education indicates that online enrollments are growing at substantially faster rates than overall higher education enrollments (12.9% vs. 1.2%), with over 3.9 million students (or over 20% of all U.S. higher education students) taking at least one online course in the fall of 2007. The study also reveals that among the eight major discipline areas examined, engineering has much lower online representation compared to others. There have been many studies on the reasons why higher education faculty choose to adopt or refrain from adopting online teaching pedagogies[2,3,4,5,6,7]. Reasons for not participating in online instruction include concerns about academic integrity, and perceptions by some faculty and administrators that online courses are not equivalent in content, rigor, and level of achievement of learning objectives when compared to the traditional, face-to-face courses[7,8,9,10,11,12,13].

There have been numerous studies done across various disciplines to determine the effectiveness of online teaching and learning[7,14,15,16,7,17,18,19,20,21,22,23]. The most comprehensive study to-date is a 2009 meta-analysis released by the US Department of Education[24] which included a systematic search for experimental or quasi-experimental studies of the effectiveness of online learning published in the literature from 1996 to 2008. This meta-analysis concluded that “on average, students in online learning conditions performed better than those receiving face-to-face instruction.” It should be noted that for studies included in this meta-analysis, the most common subject matter is medicine or health care. Other content areas include computer science, teacher education, social science, mathematics, languages, science and business. As with most previous studies on effectiveness of online instruction, engineering is not well represented.

Studies of the effectiveness of online teaching in engineering have been limited. A recent study[25] found no difference between final exam scores in the hybrid sections and the face-to-face sections of an Engineering Graphics course. Although supporting the effectiveness of online instruction in engineering, the hybrid instruction studied includes considerable (once a week) face-to-face instruction. The online portion of the course included voiced-over content presentations, software demonstrations, and sketching examples. A similar study[26] shows how the provision of online lectures, audiovisual material, discovery-based learning activities and communication tools can improve the effectiveness of subject content delivery in engineering. More studies on how online instruction in engineering can replace and be as effective as, or better than, traditional face-to-face instruction are needed.

The creation of virtual classroom space through the use of a synchronous learning environment to reduce “transactional” distance[27] has been shown to improve the quality of the educational experiences of online students[28,29,30]. This virtual classroom space can also be used to develop a dual mode of delivery to reach students online and on campus simultaneously. By assigning identical homework, exams, projects, and other course requirements to both groups of students, this dual delivery mode can address concerns regarding the equivalency of content and rigor in the online and on-campus formats. Although this dual mode of teaching also offers economic benefits, it demands extra effort from the instructor, and may prove disadvantageous for the online students[31].

The purpose of this paper is to illustrate how a dual delivery mode (content being simultaneously delivered to face-to-face and online students) can be used effectively in engineering education and with very little extra effort from the instructor. In this study, the comparability of achieving student learning outcomes for online and on-campus students in an introductory sophomore-level Circuits Analysis course will be analyzed using two years worth of data.

2. Methodology

To compare the effectiveness of dual delivery mode, specifically the comparability of the online and the on-campus courses, students in two sections each of online and on-campus formats of a sophomore-level Circuits course are compared. Comparisons of student performance in the course and usage of online resources available to both online and on-campus students are done. Additionally, a survey was administered to determine student perceptions and attitudes towards these resources and their levels of satisfaction with the course.

2.1. The Circuits Class at Cañada College

Cañada College is part of the 108-school California Community College system, and is one of the smallest community colleges in the San Francisco Bay Area with approximately 6,000 students. The college is a federally-designated Hispanic Serving Institution with approximately 42 percent Latino students. Cañada's Engineering Department is a two-year transfer program with approximately fifteen to twenty students transferring to a four-year institution every year. The Circuits course at Cañada College is a three-unit, sophomore-level lecture course required of all engineering students regardless of their majors, or their transfer institutions. The course is offered every spring semester. The class meets for three hours a week for sixteen weeks, and covers topics on theory and techniques of circuit analysis, circuit laws and nomenclature, resistive circuits, controlled sources, ideal operational amplifiers, natural and complete responses of first- and second-order circuits, steady-state sinusoidal analysis, power calculations, transformers, and three-phase circuits.

In spring semesters of 2008 and 2009, the course was offered at Cañada in dual delivery mode with lectures simultaneously delivered to on-campus and online students. All lecture notes are generated using a Tablet PC and are viewed by on-campus students through a computer projector, and synchronously by online students via the Internet.

Tablet PCs are essentially laptop computers that have the added functionality of simulating paper and pencil by allowing the user to use a stylus to write directly on the computer screen to create electronic documents that can be easily edited using traditional computer applications. This functionality makes Tablet PCs more suitable than laptop computers in presenting, solving and analyzing problems that require sketches, diagrams, and mathematical formulas. For the Circuits course at Cañada, the traditional blackboard used to generate class lecture notes has been completely replaced with the Tablet PC, allowing for synchronous delivery of content to on-campus and online students, as well as electronic copies of the lecture notes for later distribution and use.

Synchronous delivery of lectures to online students is achieved using Elluminate Live!, a multipoint videoconferencing software that is available for use free of charge to all faculty and staff of the California Community College system through CCC Confer, a project funded by a grant from the California Community Colleges Chancellor's Office. CCCC Confer allows the creation of a live interactive classroom that includes chat, electronic whiteboard, polls, quizzes and surveys, VoIP and web camera usage, application and desktop sharing, file transfer, as well presentation and sharing of documents, streaming audio and/or video. CCC Confer also allows for recording and archiving the entire session — from voice, to chat, to video, to pen strokes — during the live class, allowing everything to be played back, verbatim, and with the capability to fast forward and rewind. It also allows for sessions to be closed-captioned for the hearing impaired while also reaching out to the visually impaired by offering compatibility with most screen readers to help institutions meet state and federal accessibility guidelines. CCC Confer has allowed users to overcome the challenges videoconferencing can have, such as limited scalability, dependency on IT support, and hardware requirements.

For the Circuits course at Cañada College, links to archived CCC Confer lectures, annotated lecture notes, and additional course materials such as homework problems and solutions, sample tests, discussion boards and news forums are made available to both online and on-campus students using Moodle, an open source Course Management System. Both the online and on-campus sections of the Circuits course use the same Moodle website so that all online resources are available to both groups of students.

2.2 Comparison of Online and On-campus Students

To increase the sample size of the data and hence improve the reliability of the statistical analyses done, enrollments in the Circuits classes from two successive spring semesters are combined. The 2008 Circuits class had 15 online students and 14 on-campus students, for a total of 29 students. The 2009 class had 10 online students and 16 on-campus students, for a total of 26 students. Combining these two dual-mode classes gives a total of 25 on-line students and 30 on-campus students.

Table 1 is a comparison of the demographics of the online and on-campus students. While both groups of students are ethnically diverse, the online group has a higher percentage of female students than the on-campus group (36.0% vs. 10.0%). Both groups have Mechanical Engineering as the major with the highest number of students. However, there are significantly fewer Electrical Engineering majors in the online group compared to the on-campus group (16.0% vs. 30.0%). In fact Electrical Engineering is second only to Mechanical Engineering in popularity among the on-campus students while it is below Civil Engineering and Other among the online students, indicating that EE majors are less likely to take the class online. Additionally, a majority (83.3%) of the on-campus students were taking the lab course concurrently with the lecture course while only 12.0% of online students did so. This is significant because the lab course (also held on campus) was designed to reinforce the concepts learned in the lecture. Hence, the on-campus students have an advantage over online students in that they are able to apply and experimentally verify concepts learned in the lecture course. It should be noted that in many California engineering programs, the Circuits Lab course is required of all EE majors but not the other engineering majors.

Table 1. Demographic comparison of On-campus and Online students.

	Online		**On-campus**	
Demographics	**N**	**%**	**N**	**%**
Gender				
Female	9	36.0%	3	10.0%
Male	16	64.0%	27	90.0%
Total	25		30	
Ethnicity				
Afro-American	1	4.0%	0	0.0%
Asian	7	28.0%	10	33.3%
Caucasian	10	40.0%	8	26.7%
Hispanic	5	20.0%	7	23.3%
Other	2	8.0%	5	16.9%

Total	25		30	
Major				
Mechanical Engr	8	32.0%	12	40.0%
Civil Engr	7	28.0%	5	16.7%
Electrical Engr	4	16.0%	9	30.0%
Computer Engr	0	0.0%	2	6.7%
Other	6	24.0%	2	6.7%
Total	25		30	
Taking Lab Class				
Yes	3	12.0%	25	83.3%
No	22	88.0%	5	26.7%
Total	25		30	

Table 2 summarizes the results of a survey given to online students to understand their reasons for taking online classes, as well as any previous history of taking online courses. For the 21 online students who completed the survey, schedule conflict and convenience were the most common reasons for taking the Circuits class online. Although CCC Confer allows for students to participate in the lectures synchronously via the Internet, a majority of the online students were not able to do so due to scheduling conflicts. Additionally, a majority of the students who completed the survey would not have been able to take the class if it were not offered online, with only 23.8% responding positively to being able to take the regular on-campus class. This is significant to the viability of the course and the Engineering program at Cañada College since without the online students, the class could have been cancelled due to low enrollment in both 2008 and 2009. The survey also indicates that a majority (over 75%) of the students have taken at least one other online course.

Table 2. Summary of the survey results for selecting online versus on-campus format, and previous history of taking online courses.

Question	**Count**	**Percentage**
What is (are) your primary reason(s) for taking this class online?		
Schedule conflict with regular class	12	57.1%
Convenience	12	57.1%
Commute (I live far from Cañada College)	8	38.1%
I prefer online over face-to-face	3	14.3%
Other Reasons	6	28.6%
Would you have been able to take this course if it were not online?		
Yes	5	23.8%
No	13	61.9%
Maybe	3	14.3%
Excluding this class, how many online classes have you taken at Cañada, or any other institution?		
Zero	5	23.8%

One	6	28.6%
2-5 classes	8	38.1%
more than 5	2	9.5%

2.3 Data Analysis

To measure the effectiveness of the dual delivery mode for the Circuits course at Cañada as described above, the performance of the online and on-campus students were compared. Scores of the two groups of students on fifteen homework sets, four tests, and a final examination were compared. Identical homework problems were assigned from the textbook for both student groups. Due dates for all homework assignments were identical for the two groups of students with on-campus students submitting their work in class while online students uploaded their work through the class Moodle website. On-campus students also had the option of online submission, but this option was almost never used by on-campus students since it required an extra step of creating an electronic version of their work. All online students come to campus to take each of the four tests, as well as the final exam, either with the rest of the on-campus students, or in the campus Learning Center Testing facility. The average scores for the online and on-campus groups were computed and independent Student *t*-tests were used to evaluate the statistical significance of any differences in the performance levels of the two groups. The over-all class retention and success rates were also compared.

To determine students' attitudes towards the use of Tablet PCs and the CCC Confer (Elluminate! Live), an attitudinal survey was given to both groups of students at the end of the semester. This survey was designed to determine students' perceptions of the effectiveness of the online resources and student use of these resources. Simple averages of student responses were computed to summarize the results, and independent Student *t*-tests were used to evaluate statistical significance of any observed differences in the responses of the two groups. Online students were also asked to compare their online experience in the Circuits class with other online courses that they have taken.

3. Results

3.1 Class Performance Comparison

Table 3 shows a comparison of the performance of the online and on-campus students. For this comparison, retention rate is defined as the percentage of students who did not withdraw from the class, and hence received a grade of either A, B, C, D, or F. Success rate is defined as the percentage of students who received a passing grade (A, B, or C). The retention rates are almost the same with four students dropping from each group. The success rate of 80.0% is identical for the two groups. The online group had slightly higher Homework Average, Final Exam, and Final Course Grade, and a slightly lower Test Average compared to the on-campus students. However, there is no statistically significant difference in any of these statistics between the online and on-campus groups indicating that the online students did as well as the on-campus students.

Table 3. Comparison of the performance of online and on-campus students.

	Online (N=25)	**On-Campus** (N=30)	**Difference** (OL – OC)
Retention Rate	84.0%	86.7%	-2.7%
Success Rate	80.0%	80.0%	0.0%
Homework Average	83.5%	82.0%	1.5%
Test Average	77.7%	78.3%	-0.6%
Final Exam	79.8%	79.0%	0.8%
Final Course Grade	79.1%	79.0%	0.1%

3.2 End-of-Semester Survey

Table 4 shows a summary of the end-of-semester survey given to both online and on-campus students to determine their attitudes towards and usage of class materials and resources. Both online and on-campus students viewed the available resources positively, finding lecture notes prepared using Tablet PCs useful, Moodle (Web Access) intuitive and easy to use, archived CCC Confer lectures and CCC Confer online office hours useful, with responses of mostly between "Strongly Agree" and "Agree" when asked about the usefulness of these resources. Both groups of students preferred lectures with notes created using Tablet PCs over those using blackboard and chalk. There is no significant difference in the responses of the two groups of students in all but one survey question. When asked how they agree with the statement "I download archived CCC Confer lectures regularly," the online students' average response was 4.43 (between "Strongly Agree" and "Agree") while the on-campus students' average response was 3.27 (between "Agree" and "Neutral). The difference in the responses of these two groups is statistically significant [independent Student t-test: $t(1,42) = 4.59$, $p < .0001$)].

Table 4. Summary of results of end-of-semester attitudinal survey.

Response Scale: 5 – Strongly Agree, 4 – Agree, 3 – Neutral; 2 – Disagree, 1 – Strongly Disagree.	**Online** (N=21)	**On-Campus** (N=26)	**Difference** (OL – OC)
I find the posted instructor's lecture notes (prepared using Tablet PCs) useful.	4.63	4.8	0.17
Having access to posted notes promoted my learning.	4.63	4.82	0.20
I review the posted POWERPOINT Lecture Notes to do homework and/or study for tests.	4.68	4.68	0.00
I prefer lectures with notes created using Tablet PCs over those using blackboard and chalk.	4.05	4.28	0.23
I find Web Access intuitive and easy to use.	4.83	4.58	-0.25

The archived CCC Confer lectures are useful to me when doing homework and/or studying for tests.	4.47	4.37	0.10
I download and review archived CCC Confer lectures regularly.	4.43	3.27	1.16*
I find online office hours held using CCC Confer useful.	3.95	4.04	-0.09
I would like to have CCC Confer online office hours available for my other courses.	4.29	4.04	0.25

*Statistically significant [$t(1,42) = 4.59,\ p < .0001$)].

Since the accessing the archived CCC Confer lectures is the only area where a statistically significant difference in the responses of online and on-campus students was measured, further investigation is done. Table 5 summarizes the self-reported frequency with which online and on-campus students downloaded CCC Confer. Among online students, 66.7% indicated that they downloaded the archives regularly every week, as opposed to only 15.4% among on-campus students. The last row of Table 5 shows the average number of times these lecture archives were downloaded by each group of students as determined from actual CCC Confer records. On the average, online students downloaded CCC Confer lectures 22.5 times over the semester while on-campus students, on average, downloaded the archives only 3.8 times the entire semester. The difference between the number of times online students and on-campus students download the archives is statistically significant [$t(1,22) = 4.47,\ p < .0001$)].

Table 5. Difference in frequency of access of archived CCC Confer lectures by online and on-campus students.

I download and review archived CCC Confer lectures:	**Online** (N=21)	**On-Campus** (N=26)
Regularly every week	66.7%	15.4%
Frequently (about every other week)	14.3%	30.8%
Sometimes (about once a month)	14.3%	26.9%
Almost never (once or twice the whole semester)	4.8%	19.2%
Never	0.00%	7.7%
Actual average number of times archives were downloaded	22.5*	3.8*

*The difference, 18.7, is statistically significant [$t(1,22) = 4.47,\ p < .0001$)].

3.3 Comparison of Online Circuits Class to Other Online Classes

The end-of-semester survey also asked online students to rate their opinion of the Cañada College online Circuits class by comparing their experience in the course relative to other online classes that they have taken. Table 6 summarizes the responses of online students when asked to compare the Circuits online class to other online courses they have taken. All 16 online students who have taken other online courses indicated that the online Circuits class was much better or better compared to other online courses they have taken, with 13 out of 16 (81.3%) rating the Cañada Circuits class to be much better.

Table 6. Comparing Online Circuits class with other online courses.

Response	**Count**	**Percent**
Much better	13	61.9%
Better	3	14.3%
About the same	0	0.0%
Worse	0	0.0%
Much Worse	0	0.0%
No Opinion (no other online courses taken)	5	23.8%

4. Analysis and Conclusion

Results of the present study show that an online engineering course can be as effective as the traditional on-campus, face-to-face format. The retention rates are almost the same for the online and on-campus groups, and the success rates are identical. There is no statistically significant difference in the levels of performance of the two groups.

It should be noted that the demographic distribution of students is more favorable for the on-campus group to do better in the Circuits course compared to the online group. The percentage of Electrical Engineering majors (30.0%) in the on-campus group is about twice of that in the online group (16.0%). The Circuits course is the first course in Electrical Engineering (EE), and is therefore more important to EE majors than to students majoring in other fields of engineering. It can also be inferred that the perceived importance of the Circuits course to EE majors may be one of the reasons why fewer of them take the class online. Another advantage of the on-campus group is the number of students who were concurrently taking the laboratory class for Circuits. A majority (83.3%) of on-campus students were taking the Circuits lecture and laboratory courses simultaneously while only 12% of the online students were enrolled in the laboratory class. The laboratory class gives students opportunities to apply and experimentally verify concepts learned in the lecture course. In spite of the more favorable demographics of the on-campus group (more EE majors and more students taking the lab course), the on-line students have slightly higher (although not statistically significant) scores in homework, final exam and final course grade.

Although CCC Confer allows online students to participate in the lecture sessions synchronously via the Internet, a majority of them were not able to do so due to scheduling conflicts. To understand how the online students were able to perform as well (if not better) than the on-campus students despite not being able to attend lectures, and despite a less favorable demographics, a comparison of student usage of available class resources was done. Online students downloaded archived CCC Confer lectures about six times more frequently than on-campus students (22.5 times for online and 3.8 times for on-campus). These downloadable archived lectures allow for more flexibility in viewing through features such as rewind, fast forward, pause, etc., giving students more control of the learning process compared to listening to a live lecture. Results of previous research indicate that "conditions in which learners have more control of their learning produce larger learning gains than do instructor-directed conditions"[24]. For instance, a study done by Zhang[23] showed that simply giving students the ability to randomly access materials, allowing them to watch videos in any sequence, and to rewind and fast forward through their content, resulted in a statistically significant positive gain in learning. For the Circuits course at Cañada, even though such functionality is available to both online and on-campus students, the on-campus students rarely accessed these archived lectures.

The online students also found their learning experience in the Cañada College Circuits course better than other online courses that they have taken. A majority of them indicated that the online experience was enhanced by availability of the archived CCC Confer lectures, and the students' ability to review the archives at their own pace. It should be noted that most of the online students would not have been able to take the on-campus section of the class, and would not have been able to complete their lower-division requirements and transfer to a four-year institution in a timely manner without the online option. This is especially important for minority and female students whose pursuit of demanding professions, such as engineering and the physical sciences, are negatively affected by financial difficulties and demanding family obligations[32,33]. It should also be noted that the higher percentage of female students in the Cañada online class could be attributed these family obligations; three of the female online students are married, two of them taking care of young kids while taking the class.

Although the sample sizes used in the present study are small, results indicate that the use of dual delivery mode to synchronously deliver course content to on-campus and off-campus students can be an effective way of increasing teaching efficiency. This is particularly important for small engineering programs (particularly those in community colleges) where budget cuts and low enrollments threaten the viability of course offerings and entire engineering programs. For California community colleges in particular, this can be accomplished without any extra costs through CCC Confer.

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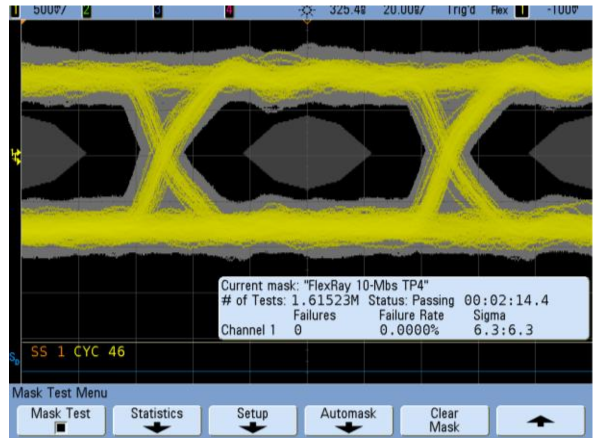
Evaluating Oscilloscope Sample Rates vs. Sampling Fidelity: How to Make the Most Accurate Digital Measurements

By Johnnie Hancock
Agilent Technologies

Introduction



Digital storage oscilloscopes (DSO) are the primary tools used today by digital designers to perform signal integrity measurements such as setup/hold times, rise/fall times, and eye margin tests. High performance oscilloscopes are also widely used in university research labs to accurately characterize high-speed digital devices and systems, as well as to perform high energy physics experiments such as pulsed laser testing. In addition, general-purpose oscilloscopes are used extensively by Electrical Engineering students in their various EE analog and digital circuits lab courses.

The two key banner specifications than affect an oscilloscope's signal integrity measurement accuracy are bandwidth and sample rate. Most engineers and EE professors have a good idea of how much bandwidth they need for their digital measurements. However, there is often a lot confusion about required sample rate — and engineers often assume that scopes with the highest sample rate produce the most accurate digital measurements. But is this true?

When you select an oscilloscope for accurate, high-speed digital measurements, sampling fidelity can often be more important than maximum sample rate. Using side-by-side measurements on oscilloscopes with various bandwidths and sample rates, this paper demonstrates a counterintuitive concept: scopes with higher sample rates *can* exhibit poorer signal fidelity because of poorly aligned interleaved analog-to-digital converters (ADCs). This paper also will show how to easily characterize and compare scope ADC sampling fidelity using both time-domain and frequency-domain analysis techniques.

In the field of academics, this paper can be first applied as a practical application and demonstration of theories presented in courses on digital signal processing. Secondly, when selecting high performance test equipment for electrical engineering and physics research labs, this paper will provide tips on how to select and evaluate digital storage oscilloscopes for accurate reproduction of captured high-speed signals.

Let's begin with a discussion of minimum required sample rate and a review of Nyquist's sampling theorem.

Nyquist's Sampling Theorem

How much sample rate do you need for your digital measurement applications? Some engineers have total trust in Nyquist and claim that just 2X sampling over the scope's bandwidth is sufficient. Other engineers don't trust digital filtering techniques based on Nyquist criteria and prefer that their scopes sample at rates that are 10X to 20X over the scope's bandwidth specification. The truth actually lies somewhere in between. To understand why, you must have an understanding of the Nyquist theorem and how it relates to a scope's frequency response. Dr. Harry Nyquist (Figure 1) postulated:

Figure 1: Dr. Harry Nyquist, 1889-1976, articulated his sampling theorem in 1928.

Nyquist Sampling Theorem

For a limited bandwidth signal with a maximum frequency f_{MAX}, the equally spaced sampling frequency f_S must be greater than twice of the maximum frequency f_{MAX}, in order to have the signal be uniquely reconstructed without aliasing.

Nyquist's sampling theorem can be summarized into two simple rules — but perhaps not-so-simple for DSO technology.

1. The highest frequency component sampled *must* be less than half the sampling frequency.
2. The second rule, which is often forgotten, is that samples *must* be equally spaced.

What Nyquist calls f_{MAX} is what we usually refer to as the Nyquist frequency (f_N), which is *not* the same as oscilloscope bandwidth (f_{BW}). If an oscilloscope's bandwidth is specified exactly at the Nyquist frequency (f_N), this implies that the oscilloscope has an ideal brick-wall response that falls off exactly at this same frequency, as shown in Figure 2. Frequency components below the Nyquist frequency are perfectly passed (gain =1), and frequency components above the Nyquist frequency are perfectly eliminated. Unfortunately, this type of frequency response filter is impossible to implement in hardware.

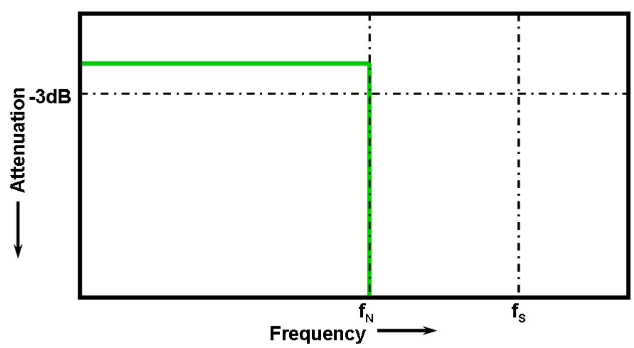


Figure 2: Theoretical brick-wall frequency response

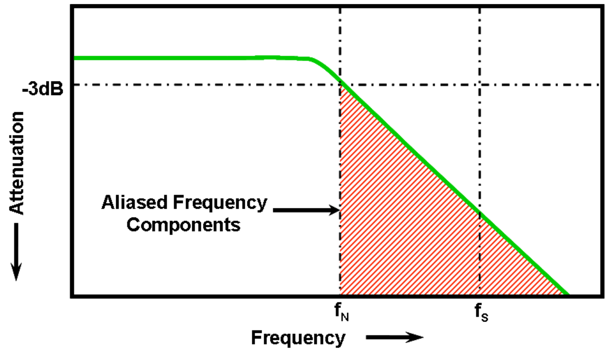


Figure 3: Typical oscilloscope Gaussian frequency response with bandwidth (f_{BW}) specified at the Nyquist frequency (f_N)

Most oscilloscopes with bandwidth specifications of 1 GHz and below have what is known as a Gaussian frequency response. As signal input frequencies approach the scope's specified bandwidth, measured amplitudes slowly decrease. Signals can be attenuated by as much as 3 dB (~30%) at the bandwidth frequency. If a scope's bandwidth is specified exactly at the Nyquist frequency (f_N), as shown in Figure 3, input signal frequency components above this frequency – although attenuated by more than 3 dB — can be sampled (red hashed area) — especially when the input signal contains fast edges, as is often the case when you are measuring digital signals. This is a violation of Nyquist's first rule.

Most scope vendors don't specify their scope's bandwidth at the Nyquist frequency (f_N) – but some do. However, it is very common for vendors of waveform recorders/digitizers to specify the bandwidth of their instruments at the Nyquist frequency. Let's now see what can happen when a scope's bandwidth is the same as the Nyquist frequency (f_N).

Figure 4 shows an example of a 500-MHz bandwidth scope sampling at just 1 GSa/s while operating in a three- or four-channel mode. Although the fundamental frequency (clock rate) of the input signal is well within Nyquist's criteria, the signal's edges contain significant frequency components well beyond the Nyquist frequency (f_N). When you view them repetitively, the edges of this signal appear to "wobble" with varying degrees of pre-shoot, over-shoot, and various edge speeds. This is evidence of aliasing, and it clearly demonstrates that a sample rate-to-bandwidth ratio of just 2:1 is insufficient for reliable digital signal measurements.

Figure 4: 500-MHz bandwidth scope sampling at 1 GSa/s produces aliased edges

So, where should a scope's bandwidth (f_{BW}) be specified relative to the scope's sample rate (f_S) and the Nyquist frequency (f_N)? To minimize sampling significant frequency components above the Nyquist frequency (f_N), most scope vendors specify the bandwidth of their scopes that have a typical Gaussian frequency response at 1/4th to 1/5th, or lower, than the scope's real-time sample rate, as shown is Figure 5. Although sampling at even higher rates relative to the scope's bandwidth would further minimize the possibility of sampling frequency components beyond the Nyquist frequency (f_N), a sample rate-to-bandwidth ratio of 4:1 is sufficient to produce reliable digital measurements.

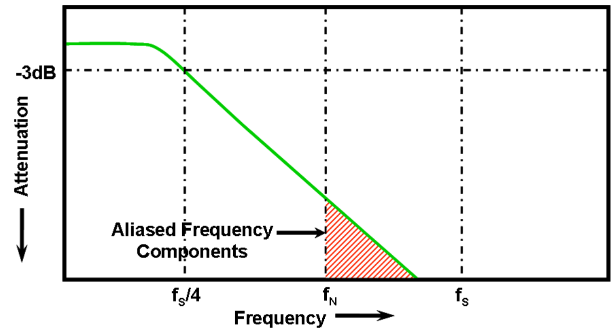


Figure 5: Limiting oscilloscope bandwidth (f_{BW}) to ¼ the sample rate ($f_{S/4}$) reduces frequency components above the Nyquist frequency (f_N)

Oscilloscopes with bandwidth specifications in the 2-GHz and higher range typically have a sharper frequency roll-off response/characteristic. We call this type of frequency response a "maximally-flat" response. Since a scope with a maximally-flat response approaches the ideal characteristics of a brick-wall filter, where frequency components beyond the Nyquist frequency are attenuated to a higher degree, not as many samples are required to produce a good representation of the input signal using digital filtering. Vendors can theoretically specify the bandwidth of scopes with this type of response (assuming the front-end analog hardware is capable) at $f_S/2.5$. However, most scope vendors have not pushed this specification beyond $f_S/3$.

Figure 6 shows a 500-MHz bandwidth scope capturing a 100-MHz clock signal with edge speeds in the range of 1 ns (10% to 90%). A bandwidth specification of 500 MHz would be the minimum recommended bandwidth to accurately capture this digital signal. This particular scope is able to sample at 4 GSa/s in a 2-channel mode of operation, or 2 GSa/s in a three- or four-channel mode of operation. Figure 6 shows the scope sampling at 2 GSa/s, which is twice the Nyquist frequency (f_N) and four times the bandwidth frequency (f_{BW}). This shows that a scope with a sample rate-to-bandwidth ratio of 4:1 produces a very stable and accurate representation of the input signal. And with Sin(x)/x waveform reconstruction/interpolation digital filtering, the scope provides waveform and measurement resolution in the 10s of picoseconds range. The difference in waveform stability and accuracy is significant compared to the example we showed earlier (Figure 4) with a scope of the same bandwidth sampling at just twice the bandwidth (f_N).

Figure 6: A 500-MHz bandwidth scope sampling at 2 GSa/s shows an accurate measurement of this 100-MHz clock with a 1-ns edge speed

So what happens if we double the sample rate to 4 GSa/s in this same 500-MHz bandwidth scope (f_{BW} x 8)? You might intuitively believe that the scope would produce significantly better waveform and measurement results. But as you can see in Figure 7, there is some improvement, but it is minimal. If you look closely at these two waveform images (Figure 6 and Figure 7), you can see that when you sample at 4 GSa/s (f_{BW} x 8), there is slightly less pre-shoot and over-shoot in the displayed waveform. But the rise time measurement shows the same results (1.02 ns). The key to this slight improvement in waveform fidelity is that additional error sources were *not* introduced when the sample-rate-to-bandwidth ratio of this scope increased from 4:1 (2 GSa/s) to 8:1 (4 GSa/s). And this leads us into our next topic: What happens if Nyquist's rule 2 is violated? Nyquist says that samples *must* be evenly spaced. Users often overlook this important rule when they evaluate digital storage oscilloscopes.

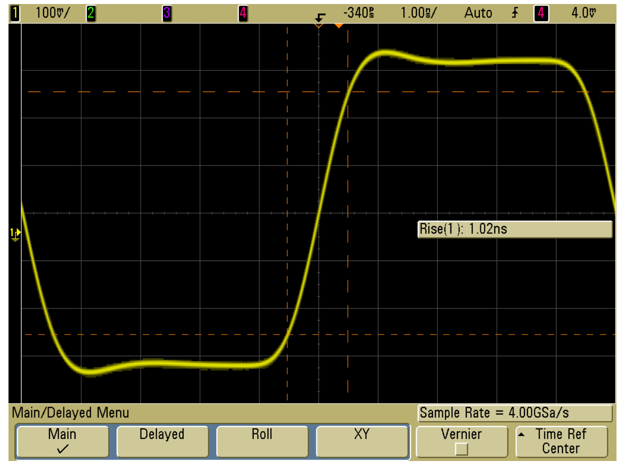


Figure 7: A 500-MHz bandwidth scope sampling at 4 GSa/s produces minimal measurement improvement over sampling at 2 GSa/s

Interleaved Real-Time Sampling

When ADC technology has been stretched to its limit in terms of maximum sample rate, how do oscilloscope vendors create scopes with even higher sample rates? The drive for higher sample rates may be simply to satisfy scope users' perception that "more is better" — or higher sample rates may actually be required to produce higher-bandwidth real-time oscilloscope measurements. But producing higher sample rates in oscilloscopes is not as easy as simply selecting a higher sample rate off-the-shelf analog-to-digital converter.

A common technique adopted by all major scope vendors is to interleave multiple real-time ADCs. But don't confuse this sampling technique with interleaving samples from repetitive acquisitions, which we call "equivalent-time" sampling.

Figure 8 shows a block diagram of a real-time interleaved ADC system consisting of two ADCs with phase-delayed sampling. In this example, ADC 2 always samples ½ clock period after ADC 1 samples. After each real-time acquisition cycle is complete, the scope's CPU retrieves the data stored in each ADC acquisition memory and then interleaves the samples to produce the real-time digitized waveform with twice the sample density (2X sample rate).

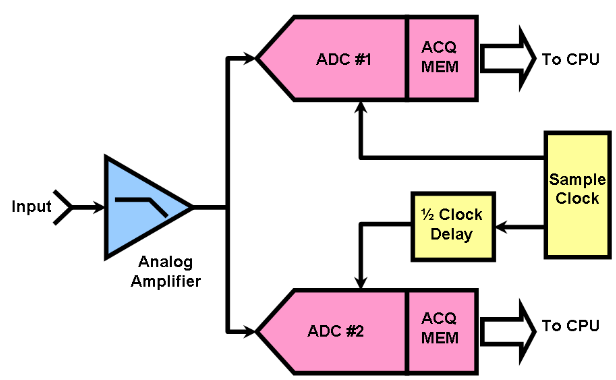


Figure 8: Real-time sampling system consisting of two interleaved ADCs

Scopes with real-time interleaved sampling must adhere to two requirements. For accurate distortion-free interleaving, each ADC's vertical gain, offset and frequency response must be closely matched. Secondly, the phase-delayed clocks must be aligned with high precision in order to satisfy Nyquist's rule 2 that dictates equally-spaced samples. In other words, the sample clock for ADC 2 must be delayed precisely 180 degrees after the clock that samples ADC 1. Both of these criteria are important for accurate interleaving. However, for a more intuitive understanding of the possible errors that can occur due to poor interleaving, the rest of this paper will focus on errors due to poor phase-delayed clocking.

The timing diagram shown in Figure 9 illustrates incorrect timing of interleaved samples if the phase-delayed clock system of two interleaved ADCs is not exactly ½ sample period delayed relative to each other. This diagram shows where real-time digitized points (red dots) are actually converted relative to the input signal. But due to the poor alignment of phase-delayed clocking (purple waveforms), these digitized points are not evenly spaced, thus a violation Nyquist's second rule.

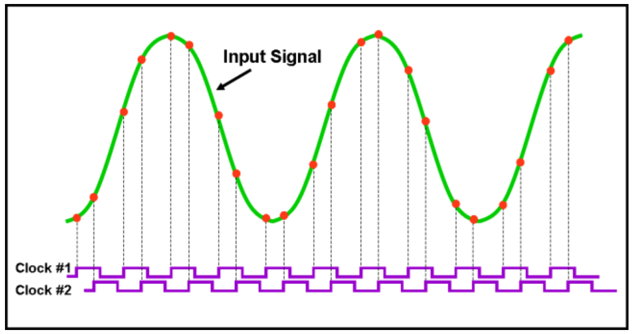


Figure 9: Timing diagram showing non-evenly spaced samples

When the scope's CPU retrieves the stored data from each ADC's acquisition memory, it assumes that samples from each memory device *are* equally spaced. In an attempt to reconstruct the shape on the original input signal, the scope's Sin(x)/x reconstruction filter produces a severely distorted representation of the signal, as shown in Figure 10.

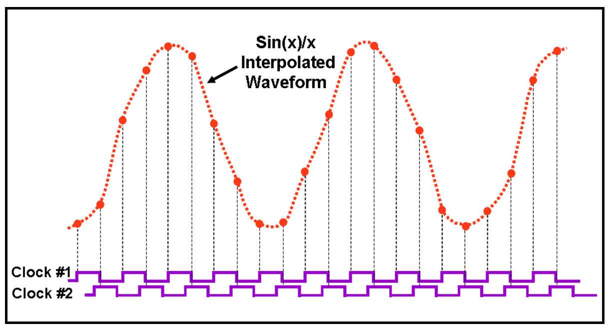


Figure 10: Timing diagram showing distorted reconstruction of waveform using Sin(x)/x filter due to poor phase-delayed clocking

Since the phase relationship between the input signal and the scope's sample clock is random, real-time sampling distortion, which is sometimes referred to as "sampling noise," may be interpreted mistakenly as random noise when you are viewing repetitive acquisitions. But it is not random at all. It is deterministic and directly related to harmonics of the scope's sample clock.

Testing for Interleave Distortion

Unfortunately, oscilloscope vendors do not provide their customers with a specification in their DSO data sheets that directly quantifies the quality of their scope's digitizing process. However, there are a variety of tests that you can easily perform to not only measure the effect of sampling distortion, but also identify and quantify sampling distortion. Here is a list of tests you can perform on scopes to detect and compare interleave distortion:

<u>Interleave distortion tests</u>

1. **Effective number of bits analysis using sine waves**
2. **Visual sine wave test**
3. **Spectrum analysis**
4. **Measurement stability**

Effective number of bits analysis

The closest specification that some scope vendors provide to quantify sampling fidelity is effective number of bits (ENOB). But ENOB is a composite specification consisting of several error components including input amplifier harmonic distortion and random noise. Although an effective number of bits test can provide a good benchmark comparison of overall accuracy between scopes, effective bits is not a very well understood concept, and it requires exporting digitized data to a PC for number crunching. Basically, an effective number of bits test first extracts a theoretical best-fit sinusoidal signal from the digitized sine wave. This sine wave curve-fit algorithm will eliminate any errors induced by oscilloscope amplifier gain and offset inaccuracies. The test then computes the RMS error of the digitized sine wave relative to the ideal/extracted sine wave over one period. This RMS error is then compared to the theoretical RMS error that an ideal ADC of "N" bits would produce. For example, if a scope's acquisition system has 5.3 effective bits of accuracy, then it generates the same amount of RMS error that a perfect 5.3-bit ADC system would generate.

A more intuitive and easier test to conduct to see if a scope produces ADC interleave distortion is to simply input a sine wave from a high-quality signal generator with a frequency that approaches the bandwidth of the scope. Then just make a visual judgment about the purity of the shape of the digitized and filtered waveform.

ADC distortion due to misalignment can also be measured in the frequency domain using a scope's FFT math function. With a pure sine wave input, the ideal/non-distorted spectrum should consist of a single frequency component at the input frequency. Any other spurs in the frequency spectrum are components of distortion. You also can use this technique on digital clock signals, but the spectrum is a bit more complex, so you have to know what to look for.

Another easy test you can perform is to compare parametric measurement stability, such as the standard deviation of rise times, fall times, or Vp-p, between scopes of similar bandwidth. If interleave distortion exists, it will produce unstable measurements — just like random noise.

Visual sine wave comparison tests

Figure 11 shows the simplest and most intuitive comparative test – the visual sine wave test. The waveform shown in Figure 11a is a single-shot capture of a 1-GHz sine wave using an Agilent 1-GHz bandwidth scope sampling at 4 GSa/s. This scope has a sample-rate-to-bandwidth ratio of 4:1 using non-interleaved ADC technology. The waveform shown in Figure 11b is a single-shot capture of the same 1-GHz sine wave using a competitive 1-GHz bandwidth scope sampling at 20 GSa/s. This scope has a maximum sample-rate-to-bandwidth ratio of 20:1 using interleaved technology.

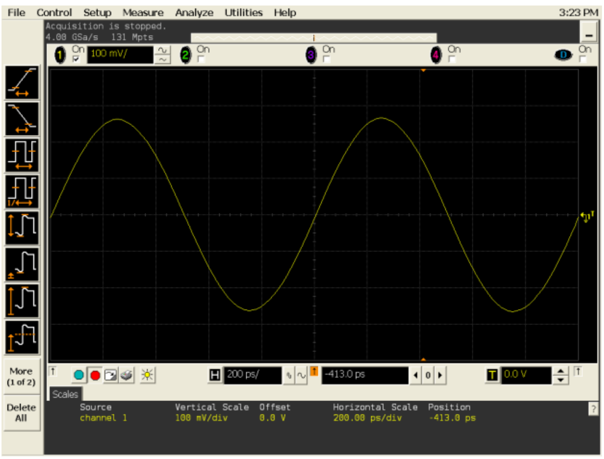


Figure 11a: 1-GHz sine wave captured on an Agilent 1-GHz bandwidth oscilloscope sampling at 4 GSa/s

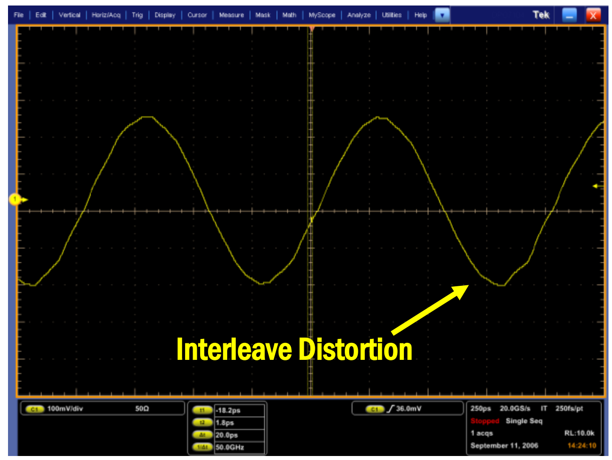


Figure 11b: 1-GHz sine wave captured on a competitive 1-GHz bandwidth oscilloscope sampling at 20 GSa/s

Although we would intuitively believe that a higher-sample-rate scope of the same bandwidth should produce more accurate measurement results, we can see in this measurement comparison that the lower sample rate scope actually produces a much more accurate representation of the 1-GHz input sine wave. This is *not* because lower sample rates are better, but because poorly aligned interleaved real-time ADCs negate the benefit of higher sample rates.

Precision alignment of interleaved ADC technology becomes even more critical in higher-bandwidth and higher-sample-rate scopes. Although a fixed amount of phase-delayed clock error may be insignificant at lower sample rates, this same fixed amount of timing error becomes significant at higher sample rates (lower sample periods). Let's now compare two higher-bandwidth oscilloscopes with and without real-time interleaved technology.

Figure 12 shows two screen-shots of a visual sine wave test comparing an Agilent 3-GHz bandwidth scope sampling at 20 GSa/s (non-interleaved) and 40 GSa/s (interleaved) capturing a 2.5-GHz sine wave. This particular DSO uses single-chip 20-GSa/s ADCs behind each of four channels. But when using just two channels of the scope, the instrument automatically interleaves pairs of ADCs to provide up to 40-GSa/s real-time sampling.

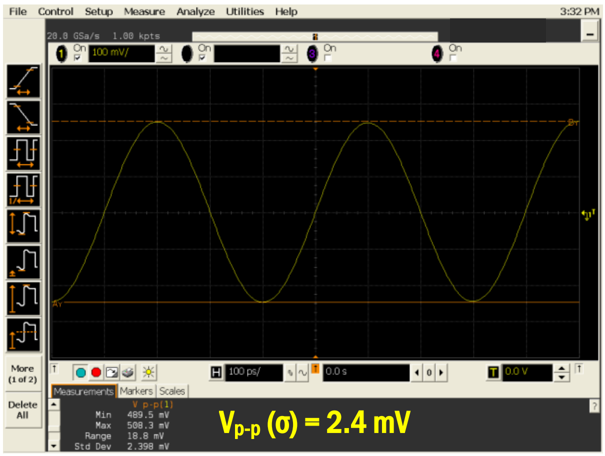


Figure 12a: 2.5-GHz sine wave captured on the Agilent Infiniium DSO80304B sampling at 20 GSa/s (non-interleaved)

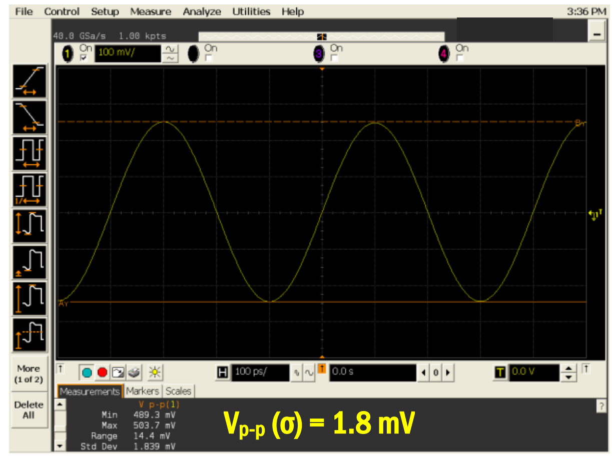


Figure 12b: 2.5-GHz sine wave captured on the Agilent Infiniium DSO80304B sampling at 40 GSa/s (interleaved)

Visually, we can’t detect much difference between the qualities of these two waveforms. Both waveforms appear to be relatively “pure” sine waves with minimal distortion. But when we perform a statistical Vp-p measurement, we can see that the higher sample rate measurement produces slightly more stable measurements – as we would expect.

Figure 13 shows a visual sine wave test comparing another vendor's 2.5-GHz bandwidth scope sampling at 10 GSa/s (non-interleaved) and 40 GSa/s (interleaved) capturing the same 2.5-GHz sine wave. This particular DSO uses single-chip 10-GSa/s ADCs behind each of four-channels. But when you use just one channel of the scope, the instrument automatically interleaves its four ADCs to provide up to 40-GSa/s real-time sampling on a single channel.

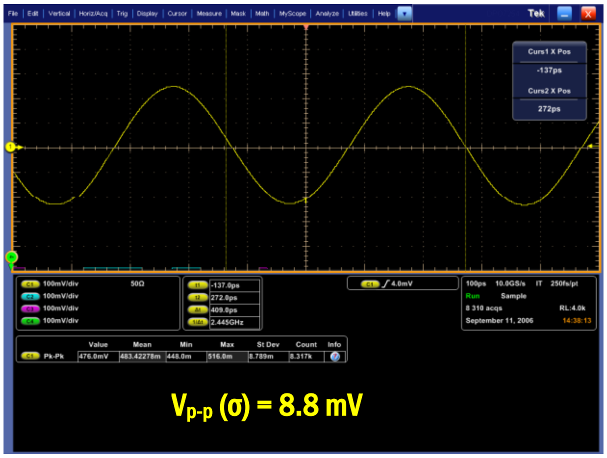


Figure 13a: 2.5-GHz sine wave captured on another vendor's 2.5-GHz bandwidth oscilloscope sampling at 10 GSa/s (non-interleaved)

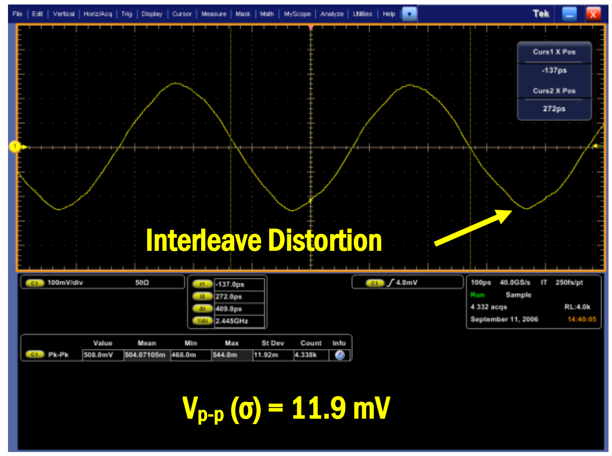


Figure 13b: 2.5-GHz sine wave captured on another vendor's 2.5-GHz bandwidth oscilloscope sampling at 40 GSa/s (interleaved)

In this visual sine wave test we can see a big difference in waveform fidelity between each of these sample rate settings. When sampling at 10 GSa/s (Figure 13a) without interleaved ADCs, the scope produces a fairly good representation of the input sine wave, although the Vp-p measurement is approximately four times less stable than the measurement performed on the Agilent scope of similar bandwidth. When sampling at 40 GSa/s (Figure 13b) with interleaved ADC technology, we can clearly see waveform distortion produced by the competitive vendor's DSO, as well as a less stable Vp-p measurement. This is counter-intuitive. Most engineers would expect more accurate and stable measurement results when sampling at a higher rate using the same scope. The degradation in measurement results is primarily due to poor vertical and/or timing alignment of the real-time interleaved ADC system.

Spectrum analysis comparison tests

The visual sine wave test doesn't really prove where the distortion is coming from. It merely shows the effect of various error/components of distortion. However, a spectrum/FFT analysis will positively identify components of distortion including harmonic distortion, random noise, and interleaved sampling distortion. Using a sine wave generated from a high-quality signal generator, there should be only one frequency component in the input signal. Any frequency components other than the fundamental frequency detected in an FFT analysis on the digitized waveform are distortion.

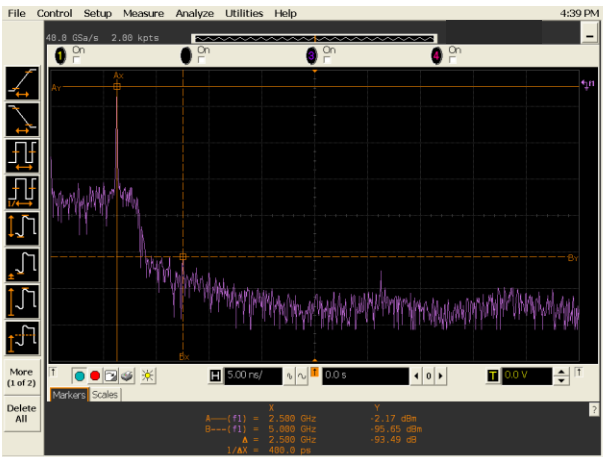


Figure 14a: FFT analysis of 2.5-GHz sine wave captured on an Agilent Infiniium DSO80304B sampling at 40 GSa/s

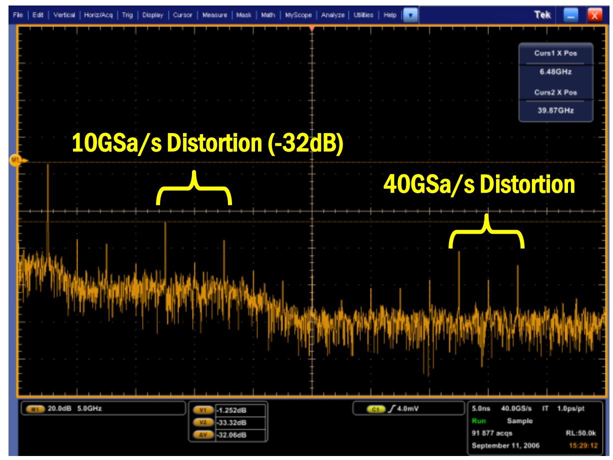


Figure 14b: FFT analysis of 2.5-GHz sine wave captured on competitive scope sampling at 40 GSa/s

Figure 14a shows an FFT analysis of a single-shot capture of a 2.5-GHz sine wave using Agilent's Infiniium DSO80304B oscilloscope sampling at 40 GSa/s. The worst-case distortion spur measures approximately 90 dB below the fundamental. This component of distortion is actually second harmonic distortion, most likely produced by the signal generator. And its level is extremely insignificant and is even lower than the scope's in-band noise floor.

Figure 14b shows an FFT analysis of a single-shot capture of the same 2.5-GHz sine wave using another vendor's competitive scope — also sampling at 40 GSa/s. The worst-case distortion spur in this FFT analysis measures approximately 32 dB below the fundamental. This is a significant level of distortion and explains why the sine wave test (Figure 13b) produced a distorted waveform. The frequency of this distortion occurs at 7.5 GHz. This is exactly 10 GHz below the input signal frequency (2.5 GHz), but folded back into the positive domain. The next highest component of distortion occurs at 12.5 GHz. This is exactly 10 GHz above the input signal frequency (2.5 GHz). Both of these components of distortion are directly related to the 40-GSa/s sampling clock and its interleaved clock rates (10 GHz). These components of distortion are *not* caused by random or harmonic distortion. They are caused by real-time interleaved ADC distortion.

Digital clock measurement stability comparison tests

As a digital designer, you may say that you really don't care about distortion on analog signals, such as on sine waves. But you must remember that all digital signals can be decomposed into an infinite number of sine waves. If the fifth harmonic of a digital clock is distorted, then the composite digital waveform will also be distorted.

Although it is more difficult to perform sampling distortion testing on digital clock signals, it can be done. But making a visual distortion test on digital signals is not recommended. There is no such thing as a "pure" digital clock generator. Digital signals, even those generated by the highest-performance pulse generators, can have varying degrees of overshoot and perturbations, and can have various edge speeds. In addition, pulse shapes of digitized signals can be distorted by the scope's front-end hardware due to the scope's pulse response characteristics and possibly a non-flat frequency response.

But there are a few tests you can perform using high-speed clock signals to compare the quality of a scope's ADC system. One test is to compare parametric measurement stability, such as the standard deviation of rise times and fall times. Interleave sampling distortion will contribute to unstable edge measurements and inject a deterministic component of jitter into the high-speed edges of digital signals.

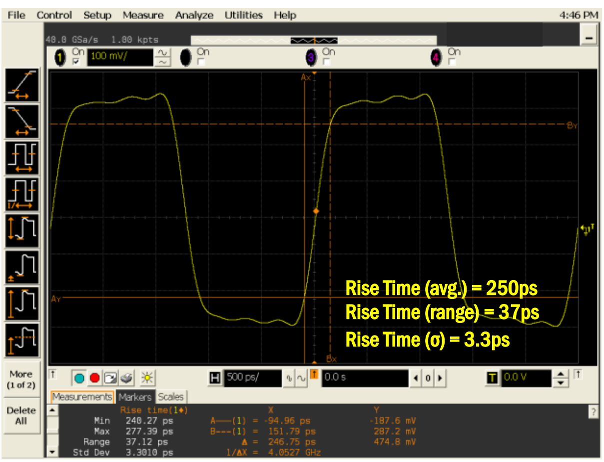


Figure 15a: 400-MHz clock captured on an Agilent Infiniium DSO80304B 3-GHz oscilloscope sampling at 40 GSa/s

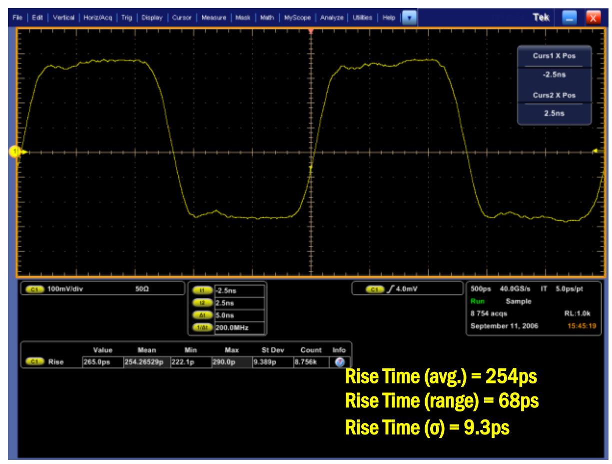


Figure 15b: 400-MHz clock captured on a competitive oscilloscope sampling at 40 GSa/s

Figure 15 shows two scopes with similar bandwidth capturing and measuring the rise time of a 400-MHz digital clock signal with edge speeds in the range of 250 ps. Figure 15a shows an Agilent 3-GHz bandwidth scope interleaving two 20-GSa/s ADC in order to sample this signal at 40 GSa/s. The resultant repetitive rise time measurement has a standard deviation of 3.3 ps. Figure 15b shows a competitive scope of similar bandwidth interleaving four 10-GSa/s ADCs in order to also sample at 40 GSa/s. In addition to a more unstable display, the rise time measurement on this digital clock has a standard deviation of 9.3 ps. The more tightly aligned ADC interleaving in the Agilent scope, along with a lower noise floor, makes it possible for the Agilent scope to more accurately capture the higher-frequency harmonics of this clock signal, thereby providing more stable measurements.

When you view the frequency components of a digital clock signal using FFT analysis, the spectrum is much more complex than when you test a simple sine wave. A pure digital clock generated from a high-quality pulse generator should consist of the fundamental frequency component and its odd harmonics. If the duty cycle of the clock is not exactly 50%, then the spectrum will also contain lower-amplitude even harmonics. But if you know what to look for and what to ignore, you can measure interleave sampling distortion on digital signals in the frequency domain using the scope's FFT math function.

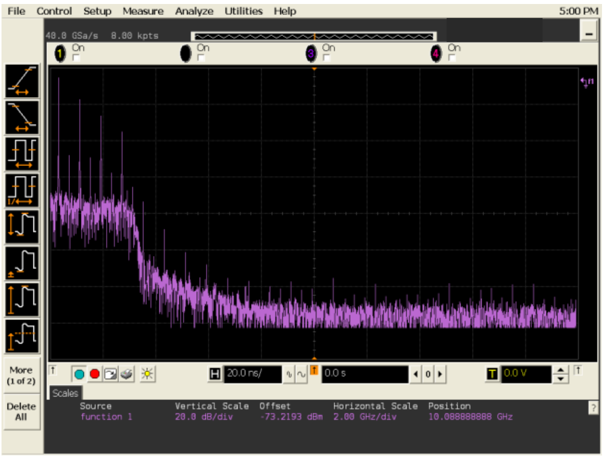


Figure 16a: FFT analysis on 400-MHz clock using an Agilent Infiniium DSO80304B 3-GHz bandwidth oscilloscope

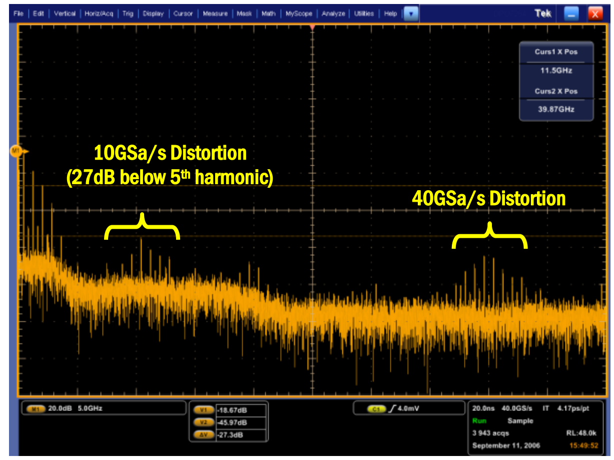


Figure 16b: FFT analysis on 400-MHz clock using another vendor's scope of similar bandwidth

Figure 16a shows the spectrum of a 400-MHz clock captured on an Agilent 3-GHz bandwidth scope sampling at 40 GSa/s. The only observable frequency spurs are the fundamental, third harmonic, fifth harmonic, and seventh harmonic — along with some minor even harmonics. All other spurs in the spectrum are well below the scope's in-band noise floor.

Figure 16b shows the spectrum of a 400-MHz clock captured on another vendor's scope — also sampling at 40 GSa/s. In this FFT analysis, we not only see the fundamental frequency component and its associated harmonics, but we also see several spurs at higher frequencies clustered around 10 GHz and 40 GHz. These imaging spurs are directly related to this scope's poorly aligned interleaved ADC system.

Summary

As you've read in this paper, there's more to oscilloscope signal fidelity than just sample rate. In some cases a lower-sample-rate scope may produce more accurate measurement results.

To satisfy Nyquist criteria, you need a scope that samples at least 3 to 5 times higher than the scope's bandwidth specification, depending on the scope's frequency roll-off characteristics. Achieving higher sample rates often requires that scope vendors interleave multiple real-time ADCs. But if real-time interleaving is employed, it is critical that the interleaved ADCs be vertically matched and the timing of phase-delayed clocking must be precise. It should be noted that the problem is *not* the number of interleaved ADCs; the issue is the level of precision of interleaving. Otherwise, Nyquist's second rule (equally-spaced samples) can be violated, thereby producing distortion and often negating the expected benefit of higher sample rates.

Work in Progress: An Applied Mathematics/Software Engineering Co-Development Project to Dynamically Predict High-Altitude Balloon Position Using Quasi Real-Time Data

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Introduction

This paper describes work in progress of a software engineering/mathematics multi-disciplinary development project in support of student ballooning. The National Space Grant Student Satellite Program[1] incorporates high-altitude balloon launches as the "crawl" phase in a "crawl-walk-run-fly" strategy of sending a student designed and built satellite to Mars. Since 2002-03, in affiliation with the Oregon Space Grant Consortium (OSGC), the LaunchOIT student balloon program at Oregon Institute of Technology (OIT) has provided a channel for undergraduate research in the "E", "T", and "S" facets of STEM (science, technology, engineering, and mathematics) education. This project intentionally incorporates the "M" facet as a major component in a software engineering project.

Software Engineering Component

In addition to an individual-based senior project, the Software Engineering Technology (SET) program at OIT requires a yearlong, team-based, junior project sequence (JP) that teaches and reinforces a disciplined, software engineering development process. This project is being executed by a 2009-10 JP team within the SET course sequence requirements along with specialized, supplemental, mathematics instruction. While SET students are required to take three courses of calculus and one course each in discrete math and calculus-based statistics, these courses are not sufficient preparation for the requirements of this project. The JP team is receiving the extra mathematics instruction in differential equations and numerical methods, which currently are not SET requirements.

The project goal is to deliver a software product whose primary function is to dynamically predict a balloon's flight path using quasi real-time position data acquired during the flight through an air-to-ground radio link implementing the Automatic Position Reporting System (APRS) protocol. Typical decision making for tracking a balloon's flight is based on static pre-flight predictions that utilize hours-old weather service sounding data. These preliminary predictions coupled with post-launch upper-air variations could lead to an ad hoc decision that places a balloon "chase" recovery team on the wrong side of a mountain or away from adequate secondary road access. These situations could prevent acquisition of GPS data down to ground level, and in turn, prevent payload recovery. This quasi real-time path prediction software system will better inform the decision making.

Mathematics Component

Typical JP projects implement some level of arithmetic computation. Computations support data capture, data base, or data presentation applications. This project, however, not only challenges a team to develop software that implements such computations, it also requires the team to co-develop a physics-based mathematical model and the algorithms that will implement the model. Success will more strongly demonstrate student learning related to the “applying mathematics” ABET TAC Outcome (b)[2].

With any mathematical model that predicts the flight of a balloon, the most significant challenge is the lack of knowledge of a wind velocity field. In this model, the team makes two assumptions about the wind. First, they assume that the balloon with payload during the ascent, and the parachute with payload during the descent, both travel at wind speed. Second, they assume that the wind velocity field is the same for both ascent and descent paths. The wind velocity field is first determined from nearby, static, pre-flight weather service sounding data. As the balloon ascends, live GPS data consisting of altitude, longitude and latitude are used to update the wind velocity field. This wind information together with a prediction of altitude provides the necessary information to predict the path of the balloon.

The altitude predictions require two different models, one for upward motion and another for downward motion. During ascent, the balloon altitude can be predicted by using that the upward velocity which is approximately constant. For the descent, the altitude predictions require that a nonlinear, second-order, ordinary differential equation be solved. Assuming a non-constant air density, the solution of the nonlinear differential equation can only be approximated by using numerical methods.

Future GPS data are acquired and used to estimate the error in the prediction algorithms. Computation of the error may require some type of curve fitting such as the method of cubic splines. As future path predictions are computed, they can be offset by utilizing the errors computed in previous predictions.

In order to guide these students toward learning the necessary mathematics and numerical methods, they are given a series of assignments starting with basic models and concluding with sufficiently sophisticated models. For example, they start with solving first-order equations with the first-order Euler method and conclude with solving a system of two first-order equations with a second-order Runge-Kutta method. The solution of this system represents the altitude and velocity of the balloon. Additional assignments on curve fitting, error analysis and unit conversions are also completed by the students. Along with weekly informal discussions, the majority of supplemental mathematics learning is accomplished by the students’ work on these assignments and their application of these new concepts within the project.

Conclusion

The SET JP sequence is scheduled to end in June 2010. While archived APRS data can spoof actual flights, a special balloon launch will be used to perform a live test of the system. In addition to being evaluated for normal software development JP sequence requirements, students will also be assessed on their engagement with the supplemental mathematics they are receiving as a part of this project.

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An Overview of Engineering Education in the US under a Globalization Environment

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Abstract

This paper reviews the current trends of engineering education in the US under globalization environment. It summarizes the requirements for global engineers, and lists the available programs that educate these engineers. It recapitulates the benefits, challenges and efforts to establish a sound global learning environment for engineering students. It concludes that the current practices by various universities will help engineering educators to create more practical, scaleable, diversified and sustainable programs in a global context.

I. Introduction

Engineering is now practiced in a global, holistic business context[1]. It is common for engineers to work on multi-national teams designing products, which will be manufactured in one part of the world and sold in another part[2]. The ever-increasing trend of economic globalization necessitates dynamic and meaningful collaboration between engineers, designers and executives, transcending political and cultural boundaries[3,4].

Today's engineering students graduate in a world that is becoming highly competitive as geographical barriers are being eliminated[5]. The engineering profession is becoming increasingly global as it moves from domestic operations to global outsourcing (subcontracts), global offshoring (overseas divisions), and more recently, global teaming[6]. Globalization is expanding the engineering labor force both by becoming more internationally diverse and more internationally mobile. Ultimately globalization is impacting all engineering graduates[5,7].

The process of globalization has created an environment where the engineering educators must do more for engineering education to influence the US economy such that the US is able to retain its leadership position[8]. Globalization requires students in the US have additional knowledge to remain globally competitive and maintain that global leadership in engineering[9]. To remain competitive, the students must develop global skills and competencies to be participants and leaders in cross-cultural engineering teams[5]. The engineering educators must mold the students to be entrepreneurs, and spirited international adventurers[10].

Globalization has gained general acceptance in engineering programs. The commonly employed lecture-based pedagogy of the 20th century is being replaced by various experiential strategies[11]. More and more engineering programs are sponsoring activities that help the students to be global[2]. However, the most recent research indicates, the American engineering students are still largely in need of skills and experience in working on an international team[3].

Globalization continues to gain prominence in the discussions on engineering education for the 21st century and beyond[12]. While United States remains a leading source of high-quality global engineering talent[13], the question currently facing American engineering educators is "How can American universities do a better job in training the global engineers for the future?" To help answer this question, this paper for the first time in the public domain provides the most complete review on the current trends of engineering education in the US under globalization environment. It summarizes the requirements for future global engineers, and lists the available programs that educate these engineers. It recapitulates the benefits, challenges, and efforts to establish a sound global learning environment for engineering students. The current practices by various universities will help engineering educators to create more practical, scaleable, diversified and sustainable programs in a global context.

II. The requirements for global engineers

Global economy requires global engineers[12]. Without a global perspective, large corporations soon become outdated and unprofitable. More and more technical staffs are being called upon, as the global engineers, to assist in technology transfers, international design collaborations, and global manufacturing issues[14]. Even though there is no consensus on the definition of "global engineers"[12], some educators believe that a global engineer should have two sets of skills, soft and technical skills[8,15,16,17, 18].

The soft skills:

- Innovation that addresses the attributes needed for success in a changing global environment;
- Entrepreneurial experience to understand consumer needs, domestic and foreign markets, and market needs;
- Multi-disciplinary and inter-disciplinary team experiences;
- Global awareness in another culture and foreign language skills;
- Awareness of professional ethics and codes of conduct;
- Communications skills, particularly across international boundaries;
- Early involvement with industry through externships, internships, co-op programs;
- Transnational mobility;
- Team leadership.

Technical skills:

- Research ability on engineering in a global context;
- Analytical skills to gather, analyze and interpret data;
- Ability to use state-of-the-art software packages and design suites;
- Technical excellence with system design emphasis;
- Ability to be a life-long learner and self-teach the subjects that will have significant impact on future employment;
- Project management skills.

III. Available programs to educate global engineers

There are at least eleven formats available in engineering programs that educate global engineers[2,19,20,21,22,23,24,25].

1. Dual degree: students obtain two degrees - one from the home university and one from the university abroad. Students follow an integrated program, which includes substantial study at the university abroad.

2. Student exchange: students from the home and university abroad are exchanged and take regular courses. A parity of exchange is maintained so there is no net expense to either institution. In student exchange program, students receive an in-depth experience associated with learning a language, living and studying abroad.

3. Field trip: it involves a 1-3 week tour including visits to foreign countries, companies, and/or universities. This type of program enables the students to obtain a "snapshot" of the world via a broad exposure to numerous places and know what issues are associated with global engineering.

4. Extension: the home university operates a pseudo-extension campus in another country. These programs usually scale more easily and can serve as a good platform from which students can explore another country.

5. Internship or co-op: students work abroad at a foreign company or at an international branch of a U.S. company. These programs can include a lot of informal learning, particularly regarding business issues involving teamwork, communication, design, and manufacturing.

6. Partner sub-contract: the home university partners with a university abroad and contracts for courses to be taught to students of the home university.

7. Project-based learning/service learning through mentored travel: students travel abroad for four or more weeks and are immersed in another culture via a project that connects technology with the society abroad. The project may involve a senior capstone project or service learning in the community abroad (such as finding water and sanitation solutions for a community that is having a high incidence of waterborne diseases; health surveys and health education for the local people).

8. Research abroad: the student travels to a laboratory abroad and conducts research under the guidance of a faculty member or research associate.

9. Faculty exchange: the faculty member from the home university teaches, or co-teaches a class of the students in the university abroad.

10. Distance learning: internet technology (web-conferencing, list-serv, emails, etc.) is used to create a virtual community for learning across cultural and national boundaries.

11. International conference: the student travels abroad to attend competitions and workshops for a short period of time, normally less than two weeks.

IV. Benefits from a global learning environment

The value of an international cognizance, in context of engineering education, has been the subject of much research[23]. It is commonly accepted that for the US to remain the world leadership in engineering and technology, it needs an educated engineering workforce that has global awareness, namely the capability of operating in international engineering and research environment[26]. The universities and students can gain quite a few benefits from a global learning environment. These benefits can be categorized as follows:

A. Study interests

In a global learning environment, the students put their roles as future professionals in the global context. It blends study abroad programs, multinational projects, courses with international experiences, globalization and international research collaboration that help the students to develop abilities beyond the traditional analytical knowledge to be competitive in the global market[21]. The students show strong learning interests and can learn a variety of topics in a short time under such a different learning environment. Nothing brings the same kind of validation, motivation, or sense of urgent reality as effectively as living and working side by side with members of a community abroad[9]. To be involved in a global learning environment also provides the students with alternative views of engineering and modern technology from a global prospective[27].

Take Western Michigan University for example. This university established a three-week program, China Summer Engineering Trip, in 2006[27]. The program included lectures, engineering field trips and engineering demonstrations. Studies of design, business, manufacturing, problem solving, quality control, and supply chain management practices were conducted. In addition, students explored trade practices, copyright and patent protections, research protocol review boards, and political practices.

B. Awareness of societal and cultural dynamics

Through service-learning projects abroad, the students will gain substantial social and cultural awareness. These projects introduce the students to open-ended problems at the community level, help the students develop the skills to solve those problems and provide holistic engineering solutions that are sustainable and appropriate to the community being served. These projects also help the students work in interdisciplinary teams, give them the opportunity to reflect on the importance of their community service, and give them a professional work ethics[28].

In 2004, students from Tufts University have initiated projects in Ecuador, El Salvador and China’s Tibet Autonomous Region. In Ecuador, the students participated in the community-based natural resource management project. In El Salvador, the students were involved in water supply and sanitation system establishment. In Tibet, the students helped the local community to build a composting latrine and a solar cooker. These international service projects aided the students in gaining an understanding of global issues that they will face in their lifetime [9].

C. Improvement of personal skills

International hands-on experiences play a key role in the development of future global engineers who can navigate the complexities of global market forces[12]. These engineers have a better understanding of the global community and the role of engineers in improving the quality of life for the people around the world. From the global learning environment, the students can obtain the following skills[12, 15,27,29,30] to:

- Work in multi-cultural teams in an international setting;
- Work in virtual teams around the world by using internet technology;
- Develop cultural awareness and understand the importance of diversity in the design and development of new products;
- Acquire, apply and strengthen the design methodology and other high-level skill sets in a global context;
- Establish an international collaborative network;
- Explore global engineering career opportunities.

At Stanford University, a capstone project in mechatronics was designed to involve international collaboration with Royal Institute of Technology, Sweden[31]. The collaboration project was found to promote:

- Disciplinary learning skills;
- General skills, such as teamwork, team management and presentation techniques;
- Awareness of cultural differences and different educational systems;
- Self-motivation to meet the challenges internationally.

D. Other long-term benefits

There are some other long-term benefits can be generated after the global learning environment is set up:

- It has been reported that the integration of global perspectives in sustainable development projects attract women and underrepresented minorities into engineering[12].

- The Accreditation Board for Engineering and Technology (ABET) requires that an engineering program must give an ability to understand the impact of engineering solutions in a global, economic, environmental, and societal context; as well as a knowledge of contemporary issues [9]. The global learning environment is seen as an opportunity to significantly strengthen the engineering program, improve ABET outcomes[5,32]. It is helpful to enhance the international reputation and quality of the university in engineering teaching, learning and research[27].

- Sustainable development is an especially important aspect of international engineering education because it is a critical element in improving the quality of life of people worldwide. Connecting international technical education with service learning enhances the understanding of societal and economic conditions in the developing world. It allows students to develop an in-depth understanding of the costs and benefits of sustainable development and globalization to communities [12].

V. Challenges from a global learning environment

Even though the global awareness is beneficial for the students to develop themselves professionally, there are many challenges to set up, sustain or survive in a global learning environment. The challenges come from five aspects.

A. Communication

Communication is the key of effective global collaboration. It is also the biggest challenge[3]. Though language courses are included in the curricula of many schools throughout the US, few students achieve any degree of fluency[33,34]. Because of the language barriers, less information is gathered, translation is required and misunderstandings are more possible[28]. The meager lingual abilities prevent a typical American engineering student from being able to discuss the work with others around the globe[33]. Aside from language, differences in thoughts and opinions are another obstacles in communication as well[3].

B. Limit of resources

Even though globalization makes international experience important, it is often difficult to achieve it as a part of engineering curriculum[35]. In recent years, there has been a movement among American universities to offer students a global experience. However, this movement has been stagnated by lack of available resources[3,11]. The high cost, which is the major factor of resources, prevents many students and faculty from participating in the international projects[25].

C. Obsolete mindsets

With the old mindsets, globalization is often related to the loss of domestic jobs and influx of international competitors and products. To change these obsolete mindsets is needed urgently and is a tough job in engineering education. Globalization should be envisioned not as a threat, but an opportunity. To meet the challenges of this new opportunity, many changes will be necessary in engineering community[5]. For example, outsourcing of some technical responsibilities to overseas should be regarded not only as an accepted practice, but also as the only way for a company to stay competitive and profitable[17].

D. Institutional constraints

At present, few universities have been intentional about integrating global, cross-cultural education into the engineering curriculum[5]. There is a lack of infrastructure at the institution level to address the following issues in the establishment of a global learning environment[3,7,21,23,24,34,36,37,38,39]:

- Scaling: The concept of globalization has not yet had widespread impact on undergraduate engineering curricula and the size is of global learning is normally small (for example, in the 2003-2004 school year, 5,548 engineering students participated in some forms of study abroad programs; in 2005-06, fewer than 7,000 American engineers went overseas for study or professional development);

- Destination restriction: most American students go to Europe and other English-speaking countries.
- Time constraint: the students are constrained by time of graduation, timing of the semester, length of internships, or credit transfer difficulty;
- Incentive for faculty: participation in these programs may not count for much in rank promotion or tenure evaluation.
- Cooperation with other departments: to set up a global learning environment involves close cooperation and adaptation of programs among various departments, such as among language programs and engineering programs. Flexibility from all departments is often required. But, departments are not always willing to bend their programs' requirements. For example, the current engineering curriculum is rigid and offers little "wiggle room". Many of these programs do not emphasize an understanding of globalization as an economic, political, or cultural phenomenon.
- Program assessment: there is no standard teaching practice in internationalized education, and it involves a whole new set of variables and experiences. There is neither enough data nor formal assessment practices in place to formally evaluate the effectiveness of these initiatives in reaching the desired objectives. Additionally, the multinational and multicultural nature make more challenging the evaluation process due to the demanding time and resources.
- Management challenges: to design and build an engineering project with the participation of multiple companies or teams from a variety of universities in the global learning environment is difficult to manage and easy to cause chaos and confusion.

E. Safety issues

Safety is always an important and sensitive issue that arises in the discussion of travel and the realization of a global project[9]. Social stability, contagious deceases and travel safety in the abroad country must be considered before any international program can take place.

VI. Efforts to build a sustainable global learning environment

A lot of universities are working hard to build a sustainable global learning environment for the engineering programs. These efforts are taken in the following seven directions.

A. Curriculum change

Some universities are integrating global issues into all years of a student's educational experience[40]. Global preparation is moved beyond "add-on" programs; knowledge of the fundamentals and dynamics of globalization as well as opportunities to be immersed in study, work, or research abroad are becoming the key elements integrated into engineering programs[41]. At John Brown University, the university core curriculum requires every student to take at least one three-hour global studies course in fulfilling degree requirements[5]. The Department of Industrial Engineering of University of Pittsburg first implemented in the U.S. an international requirement that includes an out-of-the country experience for its undergraduate students. All students in the department are required to obtain an international experience and two globally focused Humanities or Social Science courses beginning with incoming 2007-08 industrial engineering sophomores[42].

At some schools (such as Lafayette College), the educators are thinking about changing the focus in the curriculum. The areas that are not likely to be outsourced to other countries are going to be strengthened. The focus of the areas that are most likely to be outsourced is going to be minimized[17].

Some educators are advocating strengthening foreign language education. They believe that although English has spread throughout the world as an almost universal second language, the mono-lingualism and narrow focus of American engineering students does not help the students in the global setting. Brigham Young University designed an education model to teach foreign languages in the four-year's education of the engineering students[14].

B. Infrastructure and assessment process establishments

Universities have increasingly expanded their mission statements to include a commitment to producing globally competent graduates who are able to function effectively in the global marketplace and provide leadership in the international arena[34]. Many universities have had international offices or designated staff members in place to organize, facilitate and assess the globalization activities. At Virginia Tech, an international department at the Dean's level in the College of Engineering has been established in an effort to raise the percentage of engineering students to study abroad[42].

Assessment of globalization activities is being formalized as well[21]. At Georgia Tech, the Director of Assessment of the school is responsible for managing the assessment process of international internships. The assessment items include application/hiring process, students' performance on the job (pre and post internship assessment), and the job content/experience[43].

Research on assessment of globalization activities is also being undertaken. Pennsylvania State University and Florida Atlantic University proposed six steps to evaluate the learning effectiveness [21].

Step 1. Identify the need or opportunity
Step 2. Create a Faculty/Industry focus group
Step 3. Define the initiative.
Step 4. Create the Overall Assessment Design Matrix: define the goal, tasks, competencies, and outcome metrics.
Step 5. Design of assessment tools.
- a. Pre-survey
- b. Formal evaluations
- c. Post-survey

Step 6. Analysis of data and recommendations

C. Financial support from the university

Some universities provided financial support and made ambitious plan to prepare the students for globalization. At Georgia Tech, a program was launched in the fall of 2005 with a $3 million commitment from the president. The goal is to enroll 300 students per year by the year 2010. The International Plan is part of Georgia Tech's strategic plan to have 50% of its baccalaureate students graduate with international experience[41].

Some universities believe that industry leaves and sabbaticals would both promote awareness of the global practice of engineering and provide invaluable international exposure[41]. More flexibilities have been added to engineering programs for faculty to help faculty members gain international experiences and to forge partnerships at international universities. Pennsylvania State University provides faculty travel grants. These travel grants are used for a number of purposes, including supporting activities and exchanges, helping faculty acquire further funding for international programs, and assisting faculty who want to develop material for courses that have international components[23].

D. Collaboration within the university

Inter-college collaboration within a university has been shown to be successful in creating further international opportunities for engineering students[23]. University of Michigan combines a traditional undergraduate engineering curriculum with courses in business and international culture through the business and literature, science, and arts schools, respectively. Iowa State University offers programs that allow their engineering students to concurrently pursue majors in engineering and a foreign language.

E. Collaboration with industry

Industry must take the lead in developing opportunities for students to practice engineering in a global context. Universities should initiate more collaborative activities with industry, such as research, educational projects, and transnational internship programs[12,41]. Funding from private donors is the key driver of the program's potential success[44].

In 2005 – 2006, General Motors Co. and PACE (Partner for Advancement of Collaborative Engineering Education) sponsored the first international vehicle collaboration project, a senior capstone project that demonstrated how global-scale projects effectively prepare students for future exposure to large-scale collaboration projects in industry[3]. Thirteen universities around the world (including Brigham Young University) participated. Through these projects, the students learned firsthand experiences and lessons that can be effectively applied to other global collaboration projects, both industry and academia.

F. Partnerships with foreign institutions

Partnerships with foreign institutions are established to seamlessly combine the curricula and educational opportunities[45]. Some examples are[46]:

- Northern Arizona University set up a Global Engineering College where a virtual engineering college spans multiple countries and cultures.
- Iowa State University structured a Global Academic Industrial Network to create multi-organizational, international partnerships of academic and industrial organizations that emphasize collaborative educational programs and research.
- Oregon State University has International Degree Program that allows students to earn a concurrent bachelor's in International Studies associated with an engineering degree.

G. Collaboration with funding and other professional organizations

Several organizations provide financial support opportunities to help set up the global learning environment. For example, REU (Research Experience for Undergraduates) program of National Science Foundation funded University of South Florida build a 10-week summer program in computer science[47]. NCIIA (National Collegiate Inventors and Innovators Alliance) provided grant to University of Colorado at Boulder to build the course Engineering for Developing World [28].

Other professional organizations could also be helpful. For example, International Federation of Engineering Education Societies (IFEES) was launched in 2006. IFEES' mission is to foster collaboration and learning among the world's engineering education societies. Some of the resources provided by this organization include international engineering-education newsletter, annual publication profiling engineering colleges from around the world, Engineering for the World Initiative network, virtual engineering-education magazine that focuses on issues raised by globalization.

VIII. Conclusions

Globalization drives the necessity for evolution of the engineering education system. All major engineering institutions in the US are undertaking a number of approaches to develop global competency of their students. There have been eleven programs established in the US so far. A diverse, internationally competitive and globally engaged learning environment for engineering students is forming its shape in many American universities. This environment provides opportunities and challenges to the engineering students. They must work hard to be competitive globally.

There is a long way to go to establish a good global learning environment for engineering students. More fundamental research is needed to be done on student motivations, learning behaviors, learning models, organizational processes, and management methods. Change of mindsets toward globalization is important. Support, especially financial support, from the industry, university administration, faculty, students, students' parents, professional organizations and other public domains is crucial. The participation of industry in the assessment and evaluation of international experiences is also vital. Only with these necessities can the global learning environment be created and developed in a scalable and sustainable way.

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The Dismantling of the Engineering Education Pipeline

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Abstract

Community colleges play a critical role in helping to produce engineers that are urgently needed in order to maintain America's global technological competitiveness. Community colleges serve as an important pipeline for large numbers of ethnically diverse transfer students who pursue engineering degrees in four-year institutions. A few states, such as Maryland and California, have launched broad efforts to make the transfer process easier for these students. Recent developments, however, have threatened the viability of engineering programs in California Community Colleges, endangering this very important pipeline in the engineering educational system. The increasing divergence of the lower-division requirements among different four-year institutions and among the different fields of engineering has led to the erosion of what used to be a standard set of core engineering courses (graphics, statics, properties of materials, circuits, programming) that were required by all engineering programs. Additionally, the recent budget crisis has forced many community colleges to cancel low-enrollment classes and high-cost programs including those in engineering. This paper addresses the factors that have led to the gradual erosion of the lower-division core curriculum and the effects that these curriculum changes have had on community college engineering programs. It also explores the implications on the future of the engineering education system, the cost to taxpayers, and the system's effectiveness at producing the engineers that are needed to ensure that the United States remains the premier place in the world for innovation.

Introduction

The California Community College system has grown to be the largest system of higher education in the world, serving close to 3 million students every year,[1] by providing affordable and accessible education. Students are able to complete all of their lower-division coursework at a community college and then transfer to a four-year institution to complete the last two years, thus earning a bachelor's degree in approximately four years. In the 2006-2007 academic year, for instance, 55% of California State University (CSU) graduates and 28% of University of California (UC) graduates began their college years at a community college—and, upon transferring to either four-year institution, obtained GPAs equal to, or better than, "native" CSU or UC students.[1] The success of California community college transfer students is consistent with a recent national study based on a database tracking of students from 21 flagship universities showing that students who transferred from community colleges graduate at the same rate as those who enrolled as first-time freshmen, despite being more likely to be from low-income families and more likely to have not had great pre-college academic credentials.[2]
For years, this 2+2 concept worked well for community college engineering students because there was consistency in the lower-division engineering curriculum among four-year institutions.

This common set of lower-division courses, commonly referred to as “the core”, was replicated at community colleges, and students were then able to start their engineering coursework at a local community college with the option of transferring to one of the many four-year schools across the state.

Recently, the diversification of transfer requirements among university engineering programs across the state, driven partly by the continual improvement process required by ABET 2000 criteria,[3] has led to the erosion of the lower-division engineering core. This paper explores the factors that have led to the gradual erosion of the lower-division core curriculum, the effects that these curriculum changes have on community college engineering programs, and their implications on the future of the state’s engineering education system.

The Engineering Lower-Division Core

For many years, a common lower-division core curriculum allowed students to complete the first two years of their engineering education at a California Community College (CCC), and then transfer to almost any four-year engineering program in the state to complete their bachelor’s degree, often within two additional years of study. The original core curriculum had been developed by mutual agreement among representatives from CCC, UC, and CSU engineering programs, primarily under the auspices of the California Engineering Liaison Council (CA ELC), a statewide organization that has met regularly since 1947 to help steer the state’s engineering education in a manner that will facilitate transfer from two-year to four-year programs.[4] The courses that constituted the lower-division core included not only calculus, physics and chemistry sequences, but also a set of foundation engineering courses – graphics, statics, properties of materials, circuits, and programming. These courses were required of all engineering students in all four-year engineering programs regardless of major and hence an equivalent set of courses was offered by community college engineering programs, thereby often supporting one or two full-time engineering faculty.

In recent decades, however, in response to a variety of pressures (e.g., to decrease time to graduation, to replace dated courses with new courses, to increase breadth requirements, to respond to changes in accreditation criteria, etc.), well-intentioned but autonomous university engineering faculty have made independent changes to their lower-division curricula. These changes have resulted in a gradual diversification in transfer requirements for community college students. The diversification includes variability of requirements for students in the same major transferring to different institutions, as well as for students in different majors transferring to the same university.

Table 1 illustrates the variability of lower-division requirements among different engineering majors for the same institution (UC Berkeley). Although there is a high degree of uniformity in required courses in mathematics and physics, only one course (computer programming) of the core is recommended for all majors, and even that single course requirement varies slightly in content among the majors (refer to first row of Table 3). Statics is no longer required for any of the majors. Graphics and thermodynamics are both recommended for only three out of the twelve majors.

Table 1. Transfer Requirements for Various Engineering Majors at UC Berkeley*

	Calculus I, II, III	Differential Eqns & Linear Alg	Physics I, II	Physics III	General Chemistry I	General Chemistry II	Intro to Design & Analysis	Graphics	Materials Science	Solid Mechanics	Thermodynamics	Microelectronic Circuits	Intro Computer Programming	Advanced Comp. Programming	Data Structures
Bioengineering	X	X	X		X		R		R[1]			R[1]	R		
Bio/Materials	X	X	X		X		R		R			R	R		
Chemical	X	R	X		X	X			R			R	R		
Civil	X	X	X	X[1]	X	X[1]	R		R[4]	R			R		
Computational	X	X	X	X[3]	X	X[3]	R		X[3]				R		
Electrical/Comp	X	X	X	X	X		R		R			R	R	R	R
Environmental	X	X	X	X[3]	X	X[3]	X[3]						R		
Industrial	X	X	X		X		R	R[2]	R[2]	R[2]	R[2]	R[2]	R	R	
Manufacturing	X	X	X		X		R	R		R	R		R		
Materials	X	X	X	X	X	X	R		R	R			R		
Mechanical	X	X	X		X		R	R		R	R		R		
Nuclear	X	X	X	X	X		R		R			R	R		

R = Recommended X = Required [1] choose one [2] choose two [3] choose three
[4] specialized Civil Materials course only

*Data obtained from ASSIST (Articulation System Stimulating Interinstitutional Student Transfer) website assist.org. [5]

The variability of the lower-division requirements among universities for the same major is illustrated in Table 2. For Civil Engineering, although there is again a high degree of uniformity in the required courses in mathematics and physics for both CSU and UC schools, the same cannot be said regarding engineering courses. Graphics and Surveying tend to be required by CSUs but not the UCs. There is not a single engineering course that is required or recommended by all the institutions. Even the requirement for Statics, which is fundamental in the study of Civil Engineering, has deviations in two of the institutions: UC Berkeley combines it with Strength of Materials while Cal Poly SLO combines it with Dynamics.

Table 2. Transfer Requirements for Civil Engineering Majors

	Calculus I, II, III	Differential Eqns	Linear Algebra	Physics I, II	Physics III	Gen Chemistry I	Gen Chemistry II	Intro to Engineering	Graphics	Materials Science	Strength of Materials	Statics	Dynamics	Circuits	Comp/Programming	Surveying	Geology
UC Berkeley	X	X[2]	X[2]	X	X[1]	X	X[1]	R[4]		R[6]	R[2]	R[2]		R[7]	R		R
UC Davis	X	X	X	X	X	X	X			X		X		X	X	R	
UC Irvine	X	R	R	X	R	X	R	R[5]				R	R		R		
UCLA	X	X	X	X	X	X	X			R	R	R[2]	R[2]		X		
Cal Poly SLO	X	X[2]	X[2]	X	X	X	R	R[5]	R	X	R	X	R		X	R	R
CSU Chico	X	X		X	X[1]	X	X[1]	X[4]	X	X		X		X	X	X	X[1]
CSU Fresno	X	X		X	X	X		X[5]	X			X		X	X	X	X
CSU Fullert	X	X[2]	X[2]	X	X							X		X		X	
CSU LA	X	X	X	X	X	X			X	X	X	X		X	X	X	
CSU LB	X	X		X	X	X		X[3]	X	X[6]		X			X	X	
CSUS	X	X		X	X	X	X[1]		X	X		X		X[1]		X	
SDSU	X	X		X		X		X[5]				X	X			X	
SF State	X	X[2]	X[2]	X	X	X		X[3]	X	X		X	X	X	X	X	
San Jose State	X	X	X	X	X	X		X	X	X		X		X		X	

R = Recommended X = Required [1] choose one [2] combined course
[3] Careers/soft skills [4] Design [5] specialized Intro to Civil only
[6] specialized Civil Materials course only [7] microelectronic circuits

*Data obtained from ASSIST (Articulation System Stimulating Interinstitutional Student Transfer) website assist.org.[5]

Another level of variability in the required lower-division curriculum is introduced when corresponding courses at different institutions are not equivalent. For instance, although computer programming is a required or recommended course for most of the majors in most of the institutions, there is a high degree of variability in the course content among the different institutions and majors. Table 3 is a summary of the Introductory Engineering Computation/Programming transfer requirements for different majors and different institutions. As the table illustrates, the required programming language and the course content vary widely. As a result, a community college that can only offer one course of computer programming will have difficulty developing a class that can support a group of students with different majors and transfer institutions.

Table 3. Introductory Computation/Programming Requirement for Transfer Students

	Aerospace	Biochemical	Biomedical	Chemical	Civil	Computer	Electrical	Environmental	Industrial	Manufacturing	Materials	Mechanical	Nuclear	Structural
UC Berkeley	-	9	9	Any	9	10	10	9	9	9	9	9	9	-
UC Davis	-	8	8	8	8	8	8	-	-	-	8	8	-	-
UC Irvine	3	-	5	2	2	5	1	2	-	-	3	3	-	-
UC Los Angeles	2	-	2	2	2	2	2	-	-	-	2	2	-	-
UC Riverside	-	-	2	2	-	2	2	2	-	-	2	7,8	-	-
UC San Diego	2	2	2	2	-	4	1	2	-	-	-	2	-	9
UC Santa Barbara	-	-	-	6	-	4	1	-	-	-	-	6	-	-
UC Santa Cruz	-	-	-	-	-	1	1	-	-	-	-	-	-	-
Cal Poly SLO	0	-	7	-	7	2	2	6,7	7	7	6,7	6,7	-	-
CSU Chico	-	-	-	-	0	2	2	-	-	-	0	-	-	-
CSU Fresno	-	-	-	-	2	2	2	-	-	-	-	2	-	-
CSU Fullerton	-	-	-	-	0	2	2	-	-	-	-	1	-	-
CSU LA	-	-	-	-	3	-	1	-	-	-	-	3	-	-
CSU LB	2	-	-	2	2	2	2	-	-	-	-	2	-	-
CSU Sacramento	-	-	-	-	0	1	1	-	-	-	-	10	-	-
San Diego State	0	-	-	-	7	2	2	7	-	-	-	7	-	-
SF State	-	-	-	-	2	2	2	-	-	-	-	2	-	-
San Jose State	2	-	-	0	2	4	2	2	2,4	-	0	2	-	-

- Major not offered | 0. No required course | 1. C | 2. C++
3. Fortran | 4. Java | 5. Python | 6. C/MATLAB
7. Excel/MATLAB | 8. MATLAB problem-solving focus | 9. MATLAB programming
10. Other

*Data obtained from ASSIST (Articulation System Stimulating Interinstitutional Student Transfer) website assist.org.[5]

A similar situation exists with regard to the Freshman Introduction to Engineering course, some form of which is recommended or required for a majority of engineering majors. This course ranges from a 1-unit survey of career options to a 3-unit project-based introduction to design, which is in many cases discipline specific. Other more subtle differences in course content or structure abound. For example, several universities offer a combined Differential Equations and Linear Algebra course, while others require two separate courses (see Table 2). Many institutions recommend or require a circuit analysis course for a number of majors, but some require a lab while others do not. UC Berkeley requires a microelectronic circuits course, which does not articulate with the analog circuits course offered by most community colleges (and most other UC and CSU programs).

Effects of the Eroding Core on Community College Engineering Programs

The diversification of transfer requirements that has led to a "maze of standards" can be attributed to California universities' "strong tradition of faculty at each university having control of their institutions' academic programs."[6] For engineering, the diversification of the lower-division requirements has increased the number of courses that community colleges must offer, in order to maintain transfer options to different engineering majors and different universities.

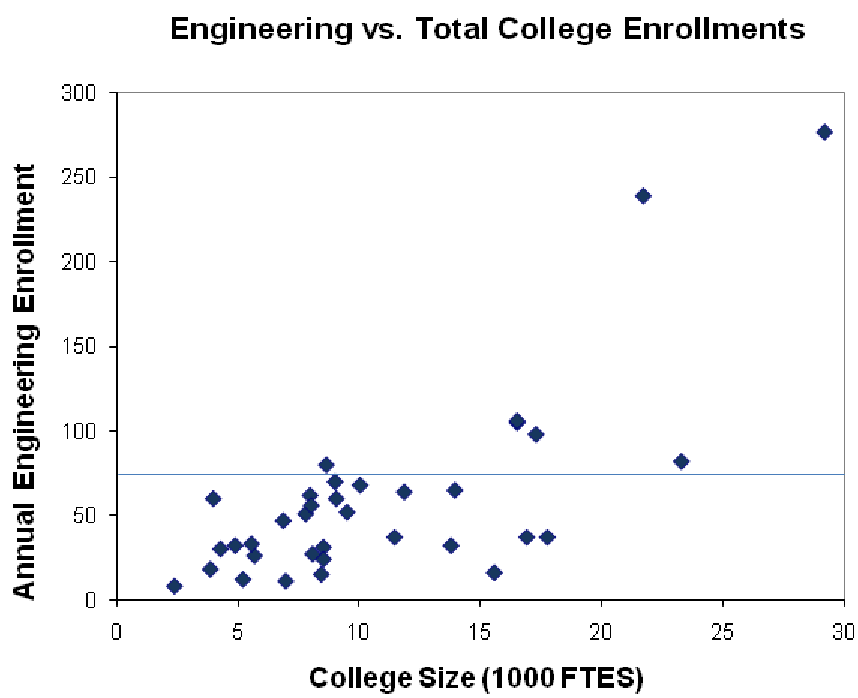

Figure 1. Annual Engineering enrollments in Circuits, Materials, and Statics classes versus overall college size for California Community Colleges. The horizontal line indicates a "healthy average enrollment" of 25 students per class. Engineering enrollment data are from CA ELC Enrollment Survey, F06-S07 or most recent complete year reported. College FTES were obtained from CCCCO Data Mart for the appropriate year.[7]

Figure 1 shows the yearly engineering enrollment in three of the "core" courses for 35 community colleges that responded to a 2007 CA ELC enrollment survey. Yearly combined enrollments in Circuits, Materials, and Statics versus college size (FTES) are shown. Of the 35 community colleges that responded to the survey, only six (or 17.1%) have healthy average enrollments of over 25 students per course. For many of these community college engineering programs, recent budget cuts have resulted in cancellation of low enrollment classes, even entire programs.

To further illustrate the effect of the erosion of the lower-division engineering core curriculum on the viability of community college engineering programs, an analysis of a hypothetical scenario is done for a typical community college in the San Francisco Bay Area that transfers an average of 25 engineering students every year. Table 4 shows the transfer requirements for four of the most popular engineering majors for four of the biggest engineering universities in the area: UC Berkeley, UC Davis, San Francisco State University, and San Jose State University. To compute the projected enrollment (last column of the table) for 25 transfer students, the following student distribution is assumed—distribution by major: 20% Civil, 15% Computer, 20% Electrical, and 30% Mechanical; distribution by transfer institution 20% UCB, 20% UCD, 20% SFSU, and 40% SJSU.

Table 4. Transfer requirements for the most common engineering majors in Bay Area universities and projected community college enrollment.

	Civil				Computer				Electrical				Mechanical				Enrollment*
	UCB	UCD	SFSU	SJSU	UCB	UCD	SFSU	SJSU	UCB	UCD	SFSU	SJSU	UCB	UCD	SFSU	SJSU	
Intro to Engr	X		X	X	X			X	X		X	X	X		X	X	18
Graphics			X	X			X							X	X	X	11
Materials		X	X	X							X			X	X	X	12
Statics		X	X	X										X	X	X	11
Solid Mech	X												X				3
Dynamics			X								X				X		4
Circuits Lect		X	X	X	X	X	X	X	X	X	X	X		X	X	X	21
Circuits Lab		X			X	X	X	X	X	X	X	X		X	X		14
Comp Prog**	X	X	X		X	X	X	X	X	X		X	X	X	X	X	20
Data Struct					X	X			X								3
Thermodyn													X				2
Surveying		X	X	X													5

*Projected enrollment for 25 transfer students with the following assumed distribution: 20% Civil, 15% Computer, 20% Electrical, and 30% Mechanical; 20% UCB, 20% UCD, 20% SFSU, and 40% SJSU.
**Required programming language and course content vary according to major and transfer institution

Out of the twelve engineering courses that are listed as required courses for at least one of the transfer institutions, only three have projected enrollments that at first glance seem high enough to be a viable class: Circuits Lecture with 21, Computer Programming with 20, and Introduction to Engineering with 18. In the case of Computer Programming, however, the aforementioned variability of the course content and programming languages required—from C++ to Java, MATLAB with problem-solving focus, MATLAB with programming focus, and Scheme—would make it difficult to design a single community college course that would be equivalent to the course required by each major and transfer institution. Similar but less severe issues exist with regard to Circuits and Introduction to Engineering. As a result, it is unlikely that any of the engineering courses could sustain an enrollment of greater than 15 students on a regular basis, making it difficult to sustain a viable engineering program.

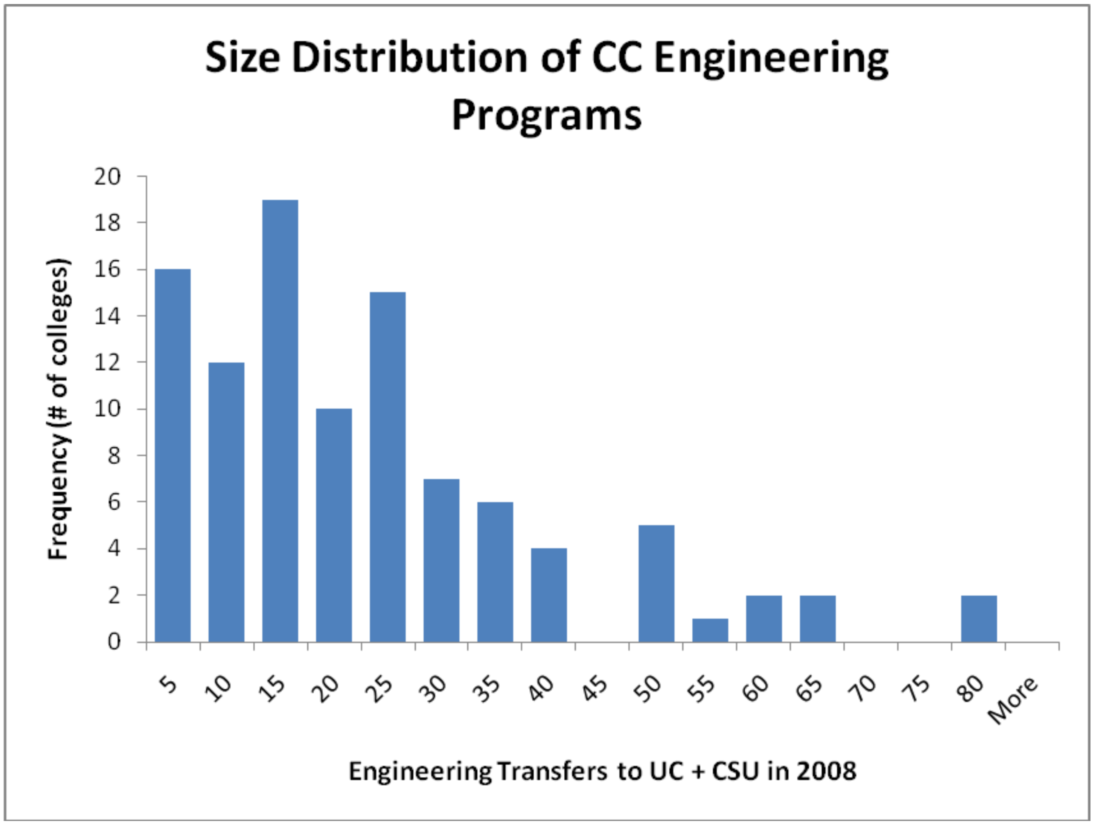

Figure 2. Distribution among individual California Community Colleges of engineering transfers to UC and CSU in Fall Term 2008. Of the 101 colleges with engineering transfers, 78 colleges transferred less than 30 students each, accounting for exactly 50% of the 2,148 total transfers. Median number of transfers = 17.0 students; Mean number of transfers = 21.3 students. Data are from California Postsecondary Education Commission.[8]

Figure 2 demonstrates that having 25 engineering transfers per year, used in the hypothetical scenario above, is in fact better than average for California Community Colleges. Of the 101 colleges with engineering transfers to UC and CSU in 2008, the average number of transfers from a college was 21.3 students (median of 17.0 students). In fact, 78 of the 101 colleges transferred less than 30 students. Based upon the course enrollment analysis above, and given current trends in transfer requirements, it is conceivable that many of these small to medium-sized engineering programs (which accounted for exactly 50% of the total 2,148 transfers) will cease to exist in the foreseeable future. Most sobering is that 44 colleges had fewer than 15 transfers each. In light of the current budget crisis in California, it seems likely that a significant number of these small engineering programs (which accounted for 17% of total transfers) will be cancelled just in the next few years.

As community colleges have become less and less able to sustain the engineering course offerings needed to meet all of the disparate requirements of the UC & CSU engineering majors, fewer and fewer transfer applicants have been able to meet these requirements. As a result, the university programs have in turn been pressured to lower their requirements for entering transfer students. For instance, UC Berkeley's lower-division engineering courses are now recommended rather than required for transfer. While this "lowering of the bar" should substantially increase the number of students who can (minimally) qualify to transfer to such programs, it will likely add as much as one year to students' post-transfer study. Given the recent fee increases and class cancellations at many universities, this may present a substantial burden both to the students and to the California taxpayers, especially if this pattern becomes the norm around the state.

Also, as more and more transfer students "take the low road" into university engineering programs, there will be further reductions in community college engineering programs and many programs will likely be eliminated altogether. This in turn will result in a less well-prepared and therefore ultimately less successful cohort of engineering transfer students, which will not only increase costs to students and the state, but is likely to further diminish representation from those groups least able to shoulder the increased burden and historically least well prepared for engineering study.

Redefining the Core

As a response to the state legislature's increasing pressure to streamline the transfer process for millions of California community college students, both the CSU and the UC systems have attempted to make the lower-division requirements more consistent. Although CSU's Lower Division Transfer Pattern (LDTP) project,[9] and UC's Intersegmental Major Preparation Articulated Curriculum (IMPAC) project[10] have had moderate success in creating common lower-division curricula for many majors, streamlining the curriculum for engineering majors has been a challenge.

For the LDTP statewide engineering pattern, there is again a high degree of uniformity in the General Education classes, as well as the required courses in mathematics and physics, but a high variability in the required engineering courses. Table 5 summarizes the required engineering courses for the statewide pattern of the LDTP curriculum for Civil, Electrical and Mechanical engineers. Out of the 45 units of courses, not a single engineering course is common to all three majors. The rest of the major-specific lower-division curriculum that is needed to complete the 60-70 units needed to transfer is campus specific, which again results in variability in the curriculum, making it difficult for community colleges to develop curriculum that is widely articulated and to maintain programs that have healthy enrollments.

Table 5. CSU Statewide Lower-Division Transfer Pattern[9] of engineering courses for the three biggest engineering majors.

	Civil	Electrical	Mechanical
Graphics	X		
Materials			X
Statics	X		X
Circuits Lect		X	X
Comp Prog		X	
Surveying	X		

The results of the IMPAC project are even less promising. The project recommends an Engineering Transfer Curriculum (ETC) base that includes the following courses:[10]

- 2 courses in Composition: English Composition, Critical Thinking/English Composition.
- 1 course in Arts or Humanities
- 1 course in Social and Behavioral Sciences (recommend US History and Government, if needed)
- 5-6 courses in Mathematics: precalculus (if needed), calculus (2 courses), multivariable calculus (1 course), differential equations (1 course), linear algebra (1 course).
- 2-3 courses in Physics: one year sequence of calculus-based physics and laboratories.
- 1 course Chemistry: college chemistry and laboratory.
- 1 course Programming: introductory programming for engineering and CS majors.
- 1 course Introduction to Engineering or Skills for Engineering Success: freshman course or choice of courses specified by the community college engineering faculty designed to expose students to engineering methodology and the excitement of engineering.
- 1 course oral communications (required for CSU, recommended for UC)

Note that the only engineering course included in ETC Base is *Introduction to Engineering*. The ETC Advanced curriculum that is yet to be developed will include additional major-specific courses, and will undoubtedly result in a transfer engineering curriculum that is as diversified and as confusing as it has ever been. In fact, the IMPAC 2005-2006 Annual Report recommends that the ASSIST web site be used as the best source of guidance for community college students who have decided on a specific engineering major and university campus.

What are our options?

1) Develop a new and improved system-wide core based on both content and student learning outcomes using the highest possible standards reasonable. This would result in system-wide articulation, along the lines of recent suggestions by Dr. Jack Scott, Chancellor of the California Community Colleges.[11]
2) Concentrate on regional articulation to make collaboration between four-year and community college faculty easier.
3) Articulate programs rather than courses.

4) Develop a solution that is process based to ensure that impacts to community colleges are understood and mitigated.
5) Increase partnership between four-year and two-year institutions. Consider:
   a. Concurrent enrollment
   b. One-to-one mutual agreements between an individual community college engineering program and a single university, which result in alignment of lower division curriculum for all majors.

Whatever the next step might be, engineering faculty at four-year schools will have to be actively involved to remedy this situation. Innovation is good but we still need consistency between approaches. At the very least, four-year schools need to work with other four-year schools (particularly those within a region) as well as with the community colleges to ensure reasonable consistency. When changes are proposed to the lower-division, the impacts to community colleges need to be evaluated and assessed before changes are finalized. To facilitate this type of collaboration a process needs to be created to assist all institutions involved.

For decades California has provided an impressive and effective community college pathway to engineering. As shown in Figure 3, approximately 33% of all UC and CSU engineering graduates in 2008 started their Bachelor's degrees at a community college (individually, 23% of UC and 41% of CSU graduates). The community college pathway therefore represents a sizeable portion of the engineering pipeline in California. For many students, particularly those from underrepresented groups, this pathway to engineering may be the only practical way for them to access an engineering education.

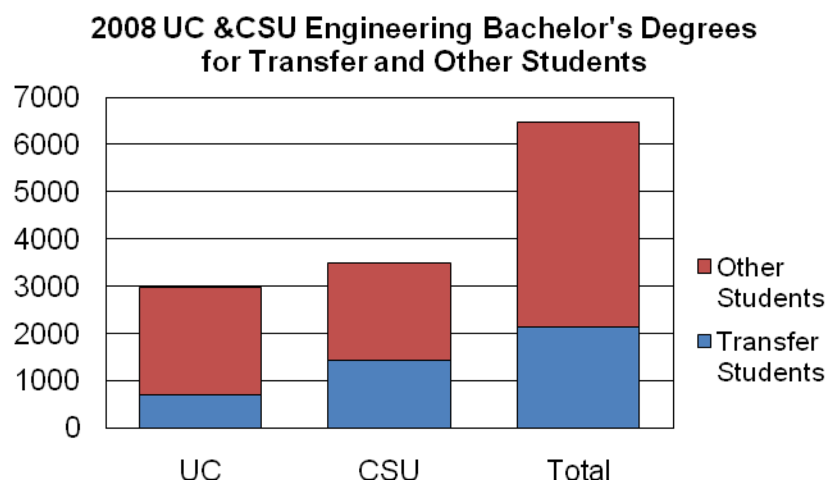

Figure 3. UC and CSU engineering graduates for 2008 showing engineering transfer students from community colleges compared to students who did not transfer from a community college. Data are from California Postsecondary Education Commission.[8]

Although this percentage is impressive, if other disciplines are considered then the percentage of transfer students at the UC and CSU schools is even higher. Figure 4 shows that among all non-engineering bachelor's degree recipients in 2008, 47% of all UC and CSU graduates were transfer students (individually, 30% of UC and 56% of CSU graduates). In other words, there is a relatively smaller representation of community college transfers among engineering graduates when compared to other majors. It is worth noting that this is not because engineering transfer students are less successful at UC and CSU. On the contrary, a 2002 UC study found that engineering transfers were actually more successful, in terms of both GPA and completion rates, than all other types of transfer students.[12] Although there may exist a number of other possible explanations for why transfer students are relatively less common among UC and CSU engineering majors, certainly among the contributing factors are the increasing complexity of engineering transfer requirements, and the decreasing availability of articulated lower-division courses at the community colleges.

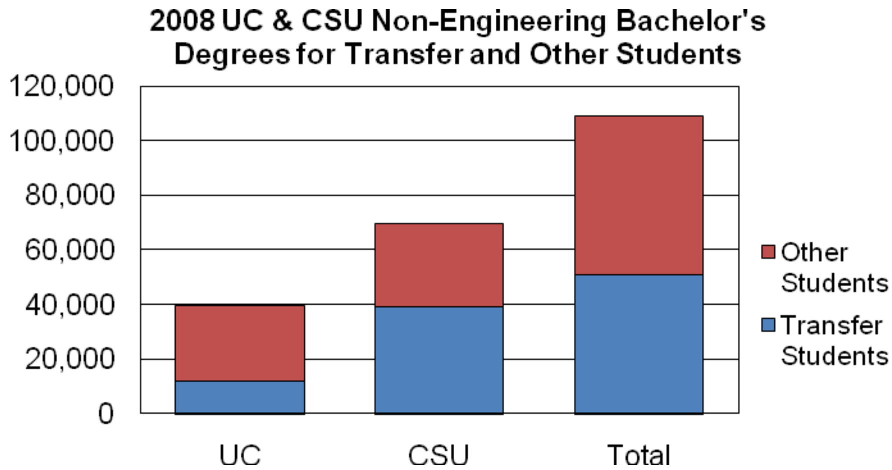

Figure 4. UC and CSU graduates in all non-engineering disciplines for 2008 showing transfer students from community colleges compared to students who did not transfer from a community college. Data are from California Postsecondary Education Commission.[8]

Education has been "the great equalizer". There have been countless positive and profound effects that an affordable higher education has had on California's economy and culture. Californians have recognized this by generously supporting the community colleges with their tax dollars, building over decades a substantial investment in the community college system. It is important therefore that the role of the community colleges be strengthened and not undermined by the work done at the four-year schools.

Most importantly, a significant number of the engineers graduating today would never have entered, much less completed, the engineering pipeline without the community college option. Although the community colleges are distributed widely across the state, they collectively play a vital role in educating engineers. The community colleges are the "open door" to higher education, providing students opportunities they never thought possible, and helping them achieve goals they never could have imagined. If the community college pathway is no longer viable for engineering students, then we have allowed our education system to become more exclusive, more expensive, and less efficient. We have dismantled a large portion of the engineering education pipeline, and have barred access to those students least likely to find a detour around the barriers we have inadvertently created.

The question we all must consider is: How many future students (many from underrepresented groups) will drop out of the engineering pipeline as the transfer system deteriorates? Can we afford the loss when the country already struggles to graduate enough engineers to sustain our global competitive advantage? The stakes are high. The good news is that this problem was solved once before, and so it can be solved again. It is time to do the essential work that is so desperately needed to preserve a higher education of open doors.

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Work in Progress: Blending Contemporary Research in Sustainability and Fundamental Skills for Graduate Success into a Team-Taught, Introductory Graduate Course

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Abstract

A team-taught graduate course titled, "EGR501: Topics in Sustainability" is required for all students pursuing a Master of Science in Engineering (M.S.E.) degree at Northern Arizona University. In the past, the course tended toward a seminar presentation style, with minimal technical depth and a light work load for the graduate students. This was due in part to the range of academic disciplines represented in the course, with instructors afraid of alienating students outside their own discipline. As with many team-taught courses, EGR501 also suffered from a lack of responsibility or accountability to any one instructor. Several department chairs and EGR501 instructors were dissatisfied with the result. The group therefore designed a new overall course structure, set of learning objectives, and instructional guidelines that would ensure specific skill development and a graduate level of work, while encouraging instructors to be pedagogically creative and to provide contemporary content. Instructors now design and submit potential modules and receive extra workload compensation for participating in the course. In addition, a course coordinator has overall responsibility for the course and tracks students' progress throughout the semester. The result has been an improvement in instructor motivation and attitudes, the quality of student products, and student preparation for successful graduate careers.

Overall Course Structure

An example overall course structure follows. Each instructor has a three-week module to discuss a specific topic related to sustainability at the graduate level. The remaining weeks are devoted to an overview of sustainability, soft skill development, and project presentations.

- *Weeks 1-2*: Introduction; Panel discussion: "What is Sustainability?"; Student project selection and planning.
- *Weeks 3-5*: Module #1 – Power Generation Techniques (Mechanical Engineering). Analysis of technical, economic, political, social, and environmental aspects of different power generation techniques. Recent innovations, current events. Life-cycle analysis.
- *Weeks 6-8*: Module #2 – Power Transmission Grid (Electrical Engineering). Challenges and emerging areas of research related to power transmission, including effects of renewable generation, efficiency improvements and behavior modification. Computer simulations of power flow in different situations. Review of recent research papers.
- *Weeks 9-11*: Module #3 – Mega-Resources (Civil & Environmental Engineering). Delineating and managing critical resource systems (Colorado River as an example). Field trip to Hoover Dam, meetings with Las Vegas water authority.
- *Weeks 12-14*: Module #4 – Sustainable Informatics (Computer Science). Techniques to manage and analyze large amounts of data, with applications to sustainability research.

- *Week 15*: Team project presentations and final reports.

Learning Objectives

The following learning objectives were developed by the department chairs and course instructors. The EGR501 students are expected to:

- Develop an appropriate research question related to sustainability.
- Conduct a high quality literature review related to sustainability research.
- Utilize project management techniques to successfully complete a research project in the area of sustainability.
- Write effective technical papers, both individually and in teams.
- Produce effective technical presentations.
- Demonstrate an understanding of and ability to utilize a variety of research techniques (e.g., analytical, numerical, and experimental) to analyze sustainability issues.
- Demonstrate a deep understanding of several important sustainability issues, including the economic, environmental, social, and legal aspects of these issues.

Instructional Guidelines

The following guidelines were provided to potential EGR501 instructors:

- Each module should have graduate level technical learning objectives related to a topic in sustainability.
- Each module should require a graduate level workload, with several hours of coursework each week.
- Each module should address effective research skills.
- Each module's assignments should be due before the first class of the following module.
- One module should require an individual report (with guidelines on effective technical reports); one module should require a technical presentation (with guidelines); one module should involve advanced simulation software (demonstrate an understanding of limitations); one module should include a field trip; consider assigning a technical poster.

Additional Modifications

Although the students performed considerably better after implementing the above structure, concerns remain, and additional modifications have been proposed. Instructors still fear alienating students outside of their discipline, so the topics and workload are still low for a graduate course. The instructors could discuss their modules with each other and the department chairs, to get feedback on ways to strengthen the content without alienating other disciplines. The students had difficulty managing their research projects and producing high quality results, even with the feedback mechanisms. The students might be more motivated by useful projects (for community or service organizations, for example) and by periodic face-to-face project status updates with instructors or their customers.

Remembering the Past to Inform the Future: Engineering and the Holocaust

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Abstract

This paper examines the complicity of the engineering community in the Holocaust, specifically, the eradication of individuals deemed undesirable by the German government. Without the cooperation of professionals on both sides of the Atlantic, the Holocaust could not have happened. The paper explores the role of key German engineering firms, such as I. G. Farben and Topf und Soehne; American involvement by the Ford Motor Company and IBM; and offers pedagogical suggestions for integrating Holocaust materials into engineering and technology classes.

While this topic is disturbing, it is important that engineering educators arm their students with knowledge of this emotionally wrenching period in history. Knowing the past may result in a brighter future.

Introduction

Sometimes, a glance into the past is painful. Engineers view themselves as educated, humane individuals who are dedicated to making the world a better place: improving living conditions, providing clean water, developing more productive agricultural methods, generating technology to enhance communications between people in the far corners of the earth. What happened to the engineering community during the Third Reich, however, gives us reason to pause and ponder.

From an engineering perspective, the Holocaust is the ultimate in problem solving: how to eliminate 11 million people (the estimated number of Jews on the planet in the 1930s) in an efficient and cost-effective manner and how to dispose of the remains in a way that would not compromise public health. The answer was the development of death camps in Poland, "a methodical blueprint for murder,"[1] the result of a brainstorming session at the 1941 Wannsee Conference. Someone, however, had to design and construct the infrastructure to support the camp system, as well as develop the instruments of death and disposal and methods for tracking the population of Europe to identify those deemed undesirable and therefore unworthy of life.

This paper begins with background information on teaching the Holocaust and examines engineering professionalism during the Third Reich. It then offers snapshots of the roles of German and American firms and ends with pedagogical suggestions for incorporating the content into engineering and technology classrooms. A note on pedagogy: this material comprises a section of "Engineering, Business, and the Holocaust," an upper-division elective at Oregon Institute of Technology. Professors who have limited time could present the firm snapshots and the information on professionalism as individual cases.

Why Teach the Holocaust?

While from a pragmatic point of view, such instruction can help engineering educators address ABET outcomes that deal with professionalism, ethics, and the societal/global impact of engineering, a deeper reason for studying this historical period involves the maintenance of civilized society in general. According to the Task Force for International Cooperation on Holocaust Education, Remembrance, and Research, founded in 1998 by Göran Persson, the Swedish prime minister, the Holocaust warrants continued study because "it fundamentally challenged the foundations of civilization."[2] Why a country as educated and cultured as Germany would chose to launch an orchestrated assault against an entire people remains one of the great puzzles of history.

The Holocaust teaches us the depths to which ordinary people may sink, lured by a seductive political ideology and the promise of renewed national pride and prominence. According to Daniel Goldhagen, author of the controversial *Hitler's Willing Executioners*, the number of people involved in the Holocaust was "greater than 100,000 and probably far greater,"[3] including camp personnel, government functionaries, *and* professionals—doctors, lawyers, teachers, engineers.

As survivors die and the Holocaust recedes further into the past, memories fade and reweave themselves into different patterns: "remembering is a social process," explains French sociologist Maurice Halbwachs.[4] If for no other reason, studying the Holocaust allows us to remember those who died, honor those who survived, and consider the true perfidy of a culture, actively supported by the professional class, for which genocide was state policy.

The Nazi Professional

Why did educated professionals join the National Socialist Party (NSDAP)? Most did so out of expediency or a renewed sense of nationalism that buoyed a devastated economy and alleviated the psychological degradation spawned by the Treaty of Versailles. Although the reasons are complex, party membership allowed the typical professional benefits otherwise unavailable. Coupled with pervasive antisemitism, an international phenomenon at that time, and a misplaced sense of patriotism, many professionals willingly embarked on a course of action that, under other circumstances, would have been unthinkable.

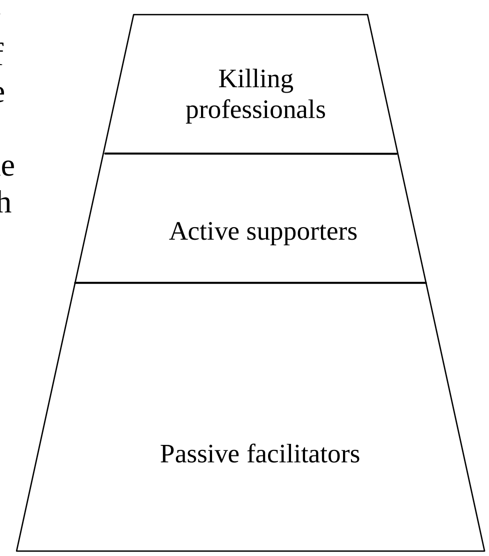

Figure 1. The professional hierarchy

Konrad Jarausch, who has written widely on the issue of professionalism in the Nazi state, arranges professional complicity into a hierarchical configuration, shown in Figure 1.[4] By far the largest group was the "passive facilitators," those functionaries who were just doing their jobs and supporting the war effort, such as the production managers overseeing the manufacture of war matériel and teachers following *völkisch* state-sanctioned curricula, which reflected the antisemitic provisions of the Nuremberg Race Laws. Hannah Arendt's comments on the "banality of evil" apply equally well to this group as to that very efficient head of Department IVB4, Office of Jewish Affairs, Adolf Eichmann.[5]

"Active supporters" included the academic class, who responded to the challenge by producing an explosion of academic support for national socialist claims of racial superiority, elevating the pseudo-science of race to legitimacy. There was, Jarausch explains, "an appalling degree of academic justification"[4] for the Nazi vision of a world free of human parasites. This group also includes aspiring young professionals such as Albert Speer, who enthusiastically embraced Nazi ideology as an opportunity to advance personal ambitions.[6]

Though in a minority, "killing professionals" were the highly educated specialists who designed and produced the technology of extermination: mechanical engineers who developed efficient crematoria for the disposition of remains, civil engineers who designed the camp infrastructures and transportation systems required for deportations, chemical engineers who developed the lethal Zyklon B, and data processing experts who provided the tabulating machines required to track the population of Europe and identify those destined for "special treatment" at the death camps in Poland.

The Nazi Engineer

A typical German engineer during the 1930s was young, male, from an urban environment, and educated, holding either a Ph.D. (for the academic class) or a TH (a diploma from a polytechnic institute). Engineers were typically employed either by government agencies or businesses affiliated with the government; very few were autonomous. In fact, in 1933, shortly after Hitler became chancellor, all existing trade unions and organizations were dissolved and reorganized, bringing them under state control, and the process of Nazification began: Jews were cast out of the professions, the civil service, and most of the trades, in accordance with the Nuremberg Race Laws.[7, 8]

Engineers tended to join professional organizations, either the VDI, for the academics, or the NSBDT, for TH graduates. About 91% of NSBDT members also belonged to the Nazi Party, as compared to only 27% of VDI members. A breakdown of NSBDT membership gives a snapshot of technical concerns of the times:

48%	machine technology & general engineering
13%	electricity, gas, & water
14%	chemistry
8%	metallurgy & mining
17%	construction[8]

Some professionals were activists; others were silent workers, those "passive facilitators" who simply carried on with their lives despite growing social tensions. Indeed, these politically disinterested but technically adept workers enabled the Holocaust, either via inertia or political apathy. They were normal men, doing normal things in decidedly abnormal times. Hartmut Topf, great-grandson of Topf founder Johann Andreas, expressed profound dismay at the dealings of his forbearers: “It makes me furious that these were my relatives . . . they were no anti-Semites, no evil Nazis. They were normal people, in a completely normal firm, which only makes it harder to understand.”[9]

Motivation and Rationale

Why would intelligent, talented engineers actively cooperate with the Nazi regime? The answer involves both economics and psychology. In the early 1920s, as fallout from losing World War I, German industry was gutted and the currency underwent a devastating period of hyperinflation. Prices rose a monthly average of 322% over a 16-month period.[10] Following a mild recovery, the Great Depression hit, and universities and technical institutes were inundated with new students. In fact, between 1925 and 1933, the number of newly-minted engineers nearly doubled, from 111,085 to 203,647; by 1933, Germany had more than 59,000 unemployed engineers.[11]

Nazi-affiliated businesses and industries offered an outlet for those experiencing the “professional drought.” Although some were drawn to the *völkisch* ideology, others saw Nazism as “the bulwark against communism.”[11] A more important reason, however, lay with the renewed emphasis on innovative technology: “The new Nazi regime was enthusiastically promoting technology and dazzled the profession with promises of recognition and substantial projects . . . such as the Autobahn and Volkswagen.”[11]

More compelling reasons lie in the psychological make-up of engineers, who, as ethicist Mike Martin suggests, tend as a whole to be more “object-centered,” regarding “people as mere things to be used or controlled.” An object orientation involves compartmentalization, detaching oneself emotionally. Commenting on Arnold Pacey’s *Meaning in Technology,* Martin identifies four different aspects of compartmentalization:

- Emotional detachment, separating “knowledge from feeling”
- “Absorption in the technical aspects of one’s work”
- “Detachment from particular groups of people”
- “Detachment from a sense of shared responsibility for the end results of technology”[12]

Rather than engaging in a Faustian pact with the devil, as John Staudenmaier suggests,[13] German engineers were able to emotionally distance themselves from the ends of their work, that is, the eradication of European Jewry. Focusing on solving the problem at hand engaged their full attention.

German Engineering Firms

It should come as no surprise that most German businesses were involved to some extent in the Holocaust, either by designing the infrastructure, producing war matériel, or exploiting the growing practice of using slave labor. Many names are recognizable to a contemporary audience, such as AEG and Siemens, electronics; BMW and Daimler-Benz, aircraft engines; Krupp, armaments; Volkswagen, weapons.[14, 15] The following discussion spotlights two companies that were intimately involved with the mechanisms of death: chemical giant I. G. Farben, which developed the Zyklon B used for mass gassings, and the firm responsible for the design and manufacture of the crematoria ovens, Topf und Soehne. Together, these two firms represent the beginning and the end of the extermination process.

I. G. Farben

In 1925, six of the largest chemical and dye firms in Europe—BASF, Bayer, Hoescht, Agfa, Cassella, and Kalle—entered into a cartel arrangement, dubbed I. G. Farben, to corner the international market on chemicals and pharmaceuticals. It was, by all counts, the largest chemical cartel in the world, eventually extending to some 880 companies in Germany and occupied lands, as well as more than 2,000 arrangements with other firms, including Dow Chemical, Standard Oil, DuPont, and Alcoa in the United States. Wall Street financiers, such as Paul Warburg, one of the founders of the Federal Reserve System, helped to fund Farben initially and were integral to its success. Antony Sutton, author of *Wall Street and the Rise of Hitler*, suggests that "without the capital supplied by Wall Street, there would have been no I. G. Farben in the first place."[16]

The companies affiliated with Farben produced an amazing array of products. Initially, the focus was on dyestuffs and chemical agents, but as the war progressed and Farben became more intimately entangled with the politics of the Third Reich, it branched out into materials required for waging aggressive war: rocket fuel and synthetics, such as oil, rubber, and nitrates.[17] Farben, in fact, was the Nazi State's primary manufacturer of war goods by 1943, producing 100% of synthetic rubber, methanol, and lubricating oil used by the Wehrmacht, as well as 88% of plastics, 84% of explosives, and 70% of gunpowder.[16] Even the plastic keys on the Enigma encryption machines were made of Farben materials.[18] Farben's complicity was so great that Senator Homer T. Bone, a Democrat from Washington, exclaimed to the Senate Committee on Military Affairs that "Farben was Hitler and Hitler was Farben."[16]

Farben affiliates employed talented scientists and engineers, including three Nobel laureates in chemistry and one in medicine, and freely used slave labor.[17] Farben chemical engineers working in the Degussa/Degesch/Bayer affiliates[19] developed neurotoxins, such as sarin, for Germany's chemical warfare program;[20] their most significant—and infamous—product, however, was Zyklon B.

Zyklon B is an insecticide, composed of prussic acid and used as a delousing agent in the camps since 1933; specifically, for the killing fleas and lice that carried the highly contagious typhus. Since prussic acid is odorless, Degesch added an irritant to make it detectable. Blankets, mattresses, and clothing were treated frequently, and the product was so lethal that, as the company manual cautioned, all treated items "must be shaken or beaten for at least one hour in the open air," and affected rooms required 24 hours airing out before use.[21]
The insecticide was restricted to fumigating non-human subjects until 1941, when Auschwitz Commandant Rudolf Hoess conducted a gassing experiment on 850 Russian prisoners in makeshift facilities. To Hoess' delight, the substance proved to be much more effective and

efficient than the carbon monoxide currently used. Degesch ramped up production and, subsequently, profits.[22] By 1942, 75% of the company's business was devoted to the manufacture of Zyklon B, a volume large enough to kill 200 million people.[16] That Degesch developers were aware of the intended use is indisputable, since they were specifically ordered to remove the irritant, rendering the substance undetectable. [22] In normal delousing use, the irritant served as a warning.

In addition to the production of Zyklon B, Farben also responded to the watime rubber shortage by building the Buna plant at Auschwitz. The plant was built by the inmates of Monowitz, a private Farben concentration camp. While most German factories had small work camps to house slave and forced laborers, Monowitz was exceptional in its size and treatment of its inhabitants. Between the brutal Polish winters and the equally brutal treatment inflicted by SS guards, 23,000 inmates—about 32 per day—died in the construction effort.[22]

Living conditions at Monowitz were horrendous: three inmates were assigned to a bed intended for one, which made sleeping impossible; food and clothing were reduced to an absolute minimum; and the work itself was so debilitating that an average lifespan at Monowitz was three to four months.[22] Meanwhile, the engineering community at Auschwitz lived in comparative luxury and continued its tasks of designing and refining the mechanisms of extermination.

An examination of I. G. Farben's complicity in the Holocaust reveals an unsettling blend of business, industry, and engineering professionals with an ideology that required the sacrifice of human lives in pursuit of a utopic vision: the world cleansed of undesirable elements and a return to idealized, mystical Teutonic roots. With the development and trade of Zyklon B, Farben played a key role in turning that vision into reality.

Topf und Soehne

In 1925, Kurt Prüfer was an ambitious young man, with a background in civil and structural engineering, when he was hired by the Erfurt firm, Topf und Soehne. Although service in World War I had interrupted his formal education, Prüfer continued at a vocational school, taking courses in civil engineering. He was promoted to engineer and by 1928 was tapped to head the "crematorium construction" division. By 1939, Prüfer had joined the NSDAP, and Topf had nearly 1,200 employees devoted to the business of death, following an arrangement with the SS.[23]

Topf was just one of many German manufacturers that played a central role in developing technology that enabled the Holocaust. Founded in 1878 by master brewer Johann Andreas Topf, before World War I Topf became one of the major producers of malting equipment for breweries, including "boilers, chimneys and silos . . . ventilation and exhaust systems."[24] By the beginning of the war, the company had branched out to producing municipal crematorium ovens; Germany, like France, favored cremation over burial.[23] Topf promised "the utmost in dignity," by using "technically outstanding methods" that produced neither smoke nor odor. [24]

Dignity disappeared in 1939, when Prüfer was approached by the SS with a request to build a crematorium for the nearby Buchenwald concentration camp, to deal with the remains of hundreds of prisoners killed by an epidemic.[9] That began a long, productive partnership between Topf and the SS, willingly entered into and sustained with, apparently, no moral qualms: "there were evidently no moral or ethical bounds to be overcome or whittled down in a lengthy process of stupefaction and brutalization."[24]

In fact, Prüfer, along with engineers Fritz Sander and Karl Schultze, enthusiastically introduced truly innovative, industrial-strength crematoria, including an oven with 46 chambers capable of processing 1,440 bodies a day.[23] Prüfer earned the nickname "The Wizard of Cremation" for his efforts, [25] and, in a 1941 letter to Topf owners, he even asked for a raise: "These furnace constructions pioneer the way for the future and I venture to hope that you will grant me a bonus for the work involved."[23] On Christmas Eve, he received his bonus, a handsome 150RM, or about $1,000 in contemporary dollars, followed by another 450RM ($3,000) shortly thereafter.[23]

Topf supplied the crematorium ovens for two of the Polish death camps—Auschwitz-Birkenau and Majdanek—as well as several POW camps that housed captured Soviet soldiers. In addition, the company designed more than 20 ovens for several concentration camps located in Germany and Austria: Dachau, Ravensbruck, Sachsenhausen, Flossenberg, Mauthausen, and Stutthof.[23] Surprisingly, oven manufacture accounted for only 1-2% of overall Topf profits,[24] hardly enough to justify the obvious zeal with which the engineers approached their tasks. Prüfer, Sander, and Schultze were certainly aware of how their designs were being used; in post-war interrogations, all three freely admitted that they had visited Auschwitz numerous times to observe their creations in operation. Prüfer, in fact, noted that he had known "since spring 1943 that innocent human beings were being liquidated in Auschwitz gas chambers and that their corpses were subsequently incinerated in the crematoriums [*sic*]," and, furthermore, "I was aware of the fact that my work was of great importance for the national socialist state."[26]

Karl Schultze designed the ventilation systems for the ovens, and, of the three, he was the only one who offered the "I-was-just-doing-my-job" defense: "I only respected and acted according to the laws of my country." Despite having visited Auschwitz three times, he claimed that he was unaware that civilians were being liquidated; he thought the remains of criminals, specifically Poles who committed crimes against the German army, were being burned. On further questioning, the real reason emerged: "I was afraid of losing my position and of possible arrest."[26]

By far the most chilling comments came from Fritz Sander, who, in 1942, designed a new, higher capacity crematorium based on a conveyor belt principle, thus obviating the need for the *Sonderkommando,* the Jewish inmates who attended to the gas chambers and ovens. Using his design, Topf completed and submitted a patent application, although manufacture was never carried out, due to a problem with the belt material's ability to withstand the constant, intense temperatures. When queried why he could, in good conscience, so passionately pursue a design for such a device, Sander responded, "I was a German engineer and key member of the Topf works and I saw it as my duty to apply my specialist knowledge in this way in order to help

Germany win the war, just as an aircraft construction engineer builds airplanes in wartime, which are also associated with the destruction of human beings."[26, 27]

Like I. G. Farben, Topf und Soehne was a key player in advancing Nazi claims of racial superiority. Without Topf's very efficient ovens, the Polish death camps would have been drowning in bodies—so many that effective disposal was out of the question. Prüfer, Sanders, and Schultze were talented engineers, but they used their skills to the detriment of humanity.

American Involvement

One expects German companies to support their country's political vision; however, discovering that American firms were also complicit is a bit more unsettling. This discussion examines two major US firms with long-standing commitments to Germany, the Ford Motor Company and IBM. Both used their technical staffs to support the Nazi vision, while, in keeping with spirit of capitalism, reaping enormous profits during the war years.

Ford Motor Company

The Ford Motor Company was but one of many American businesses operating profitably within the Third Reich; others included Standard Oil, General Motors, General Electric, Texaco, and several banks.[16] What distinguishes Ford, however, is the owner's ideological compatibility with Nazi philosophy and his willingness to consciously ignore moral dictates in favor of profiteering.

Henry Ford was a great inventor and a brilliant businessman. Not as well known, however, were his decidedly antisemitic sentiments. The first documented evidence dates to 1915, and by 1920, his beliefs were sufficiently developed to announce them to the world via a series of articles in the weekly *Dearborn Independent*, a Ford-owned newspaper. The 91 tracts were based on *The Protocols of the Learned Elders of Zion*, an acknowledged forgery that details the Jews' plans for world domination.[28]

To ensure wide dissemination, Ford employees tucked copies of the newspaper in the glove box of each new vehicle as it rolled off the assembly line.[29] Eventually, the articles were anthologized in four volumes as *The International Jew*, allowing some two million readers[30] a glimpse of Ford's peculiar view of history as driven by fanatical Zionists.[28]

The International Jew made its way to Germany in the early 1920s and captured the attention of a fledgling Nazi hierarchy: future head of the SS, Heinrich Himmler, said that "Ford's book had opened his eyes to the Jewish danger";[28] Baldur von Schirach, Hitler Youth leader, noted, "You have no idea what a great influence this book had on the thinking of German youth . . . if [Henry Ford] said the Jews were to blame, why naturally we believed him."[31]

Even Adolf Hitler praised Ford. In *Mein Kampf,* Ford was depicted as the lone individual who could fend off Jewish financiers controlling Wall Street.[32] Hitler actually had a life-sized portrait of Ford hanging by his desk in his Munich office. "I regard Henry Ford as my inspiration," he commented to a *Detroit News* reporter in 1931.[31] In fact, Hitler was so taken with Ford's writings that he unabashedly copied portions and incorporated them into Volume 2 of *Mein Kampf*.[32]

With ideology in harmony with that of the Third Reich, Ford's next venture was to begin business operations, opening an office in Berlin in 1925, a factory in Cologne in 1931,[29] and a plant in Berlin in 1935.[33] Christened "Fordwerke," the factories produced light trucks as well as the passenger vehicles required by the SS, police, and members of the Nazi hierarchy. By 1941, Fordwerke **only** produced military trucks and was one of the Wehrmacht's "largest suppliers," manufacturing about 30% of the trucks required by the German Army for its blitzkrieg strikes.[34]

Despite its location in an enemy country, Fordwerke remained an American corporation, with 52% of its stock held by Dearborn.[29] By 1943, about half of the plant's "employees" consisted of slave or forced labor, who worked an average of 12 hours a day and were provided "200 grams of bread for breakfast, no lunch and a supper of spinach and three potatoes or soup made of turnip leaves."[34] This was consistent with the operations of German labor camps, such as Monowitz, which offered inmates a starvation diet of about 184 calories a day.[35]

Although some historians disagree,[36] the Ford Motor Company profited from both sides during the war: it produced vehicles for the Axis in its European facilities and manufactured bombers for the Allies at its Dearborn plant.[29] In fact, Fordwerke realized a profit of more than $2.5 million ($77.5 million in contemporary dollars) during the war. Even taking into consideration losses in 1945, the company still reaped a handsome profit of over $1 million dollars ($12 million in contemporary dollars).[37] Moreover, after the war, the company received nearly $1 million ($12 million) in reparations for damages incurred to its plant during the bombing of Cologne.[28]

The most important technological contribution of the Ford Motor Company to the Holocaust was providing the concept of the assembly line process. According to Ford's memoirs, the idea first occurred to him in a Chicago slaughterhouse: "The idea came in a general way from the overhead trolley that the Chicago packers use in dressing beef."[38] While this process revolutionized industrial manufacturing, it also proved an efficient and cost-effective way for handling the huge number of bodies in the death camps. It was far superior to the practice of mass burials, which posed a significant threat to public health. As Charles Patterson observes, Henry Ford's "impact on the twentieth century began, metaphorically speaking, at an American slaughterhouse and ended at Auschwitz."[31] People were processed like cattle.

While other US businesses also profited handsomely from ventures with the Third Reich, the Ford Motor Company will be remembered for the founder's "energetic cooperation"[31] with a morally bankrupt totalitarian regime and for providing the concept of the assembly line process used in the death camps, enabling a culture of death to flourish.

IBM

The role of IBM in the Holocaust differs dramatically. Whereas Ford's initial involvement was based on ideological compatibility, IBM's motives were more commercial. Ford produced tangible goods to support the war effort; IBM dealt in a more ethereal substance: information. However, the collection and processing of information proved more influential to accelerating the Holocaust than did Ford's war machinery.

The German census of 1933 was the most comprehensive in the country's history, due, primarily, to the use of Hollerith tabulating machines.[39] Herman Hollerith, a brilliant young engineer working as an assistant at the US Census Bureau, won a bureau-sponsored competition in 1890 by inventing an automated counting machine capable of processing large amounts of information in a relatively short period of time.[40] Using columned cards, operators punched holes to represent different traits; the cards were then fed into a reader that tabulated the information.

Realizing the commercial potential of his invention, Hollerith incorporated; in 1911, his Tabulating Machine Company merged with two others, and, in 1924, emerged as International Business Machines Corporation, to reflect the company's new character. IBM's first major foreign foray was in Germany, where its subsidiary was known as Dahomag.[41]

In 1914, Hollerith withdrew as general manager and appointed Thomas J. Watson, an energetic and aggressive National Cash Register employee, in his stead. Unlike Henry Ford, Watson made no public pronouncements of his antisemitic leanings, although he was "clearly a friend to Hitler."[42] A ruthless salesman, Watson was a formidable personality who required "absolute loyalty and ceaseless devotion from everyone."[41] He regularly held revival-style meetings, with employees chanting the IBM anthem, and the company even had the IBM Club, its version of a youth movement. Children were eligible for enrollment at age three, starting their indoctrination in the IBM way as early as possible.[41]

Under Watson's leadership, IBM became the dominant international force in data processing, eventually placing its machines in more than 78 countries and controlling 90% of the world market.[41] Since the company rented its equipment, IBM New York retained control and performed all maintenance. Dahomag, limping along since its 1922 affiliation with IBM, suddenly soared under Watson's sharp eye. By the time the NSDAP rose to power in 1932, its performance was deemed "spectacular."[41]

"Statisticians," notes Edwin Black, were "the vanguard of Hitler's intellectual shock troops."[41] Purveyors of numbers in the Third Reich quickly realized the potential of the Hollerith tabulators to identify Jews and other political undesirables. Will Heidinger, manager of Dahomag operations and a fervent Nazi, characterized the quest for information as "almost a sacred action."[41]

The Nazis went statistics crazy. They started counting everything: people, religions, businesses, occupations, diseases, war material dispersal–even cows in the field. They used millions of punch cards a week, further enriching IBM's coffers, since all Hollerith customers were required to buy their cards from the parent company. Germany was IBM's best foreign customer, and Hollerith machines were placed in government offices and concentration camps, where they kept track of the population as well as deaths. Between 1933 and 1939, the Third Reich installed over 2,000 IBM tabulators, sorters, and printers in statistical centers throughout Germany, with 24 alone in the Dachau concentration camp.[43] By 1943, Reich statisticians were using almost 1.5 billion punch cards annually to catalog the population of Europe.[41]

During processing at the camps, those destined for labor details would have their Hollerith number tattooed on their forearms. Although the tattooing system in Auschwitz was eventually divorced from its Hollerith connection,[41] the fact that it was originally intended for data processing certainly testifies to the Germans' exactitude regarding record-keeping.

When Germany invaded Poland in 1939, IBM established a new subsidiary, Watson Business Machines, in Kraków to coordinate deportations to Treblinka and Auschwitz. "Its sole purpose," suggests Black, "was to service the Nazi occupation during the rape of Poland."[44]

IBM remained heavily involved even after the US officially entered the war and instituted business sanctions against the Third Reich. Rather than reporting to New York, European subsidiaries reported to IBM in Geneva, which forwarded the information to New York headquarters.[44]

IBM's contribution of the immensely valuable and indispensable punch card technology had the affect of accelerating Holocaust events.[46] Although the Holocaust surely would have happened without IBM's complicity, it would have been grossly inefficient and taken longer. For example, in France, which had no punch card technology, about 23% of Jews were killed. But 73% were killed in Holland, which had "the most sophisticated technology outside of Germany."[43] The Hollerith tabulators allowed the Nazis to document virtually everything. From information on the cards, they were able to generate lists of Jews in almost any location, ghettoize them, schedule deportations, route trains to deliver Jews to the death camps in Poland as well as distribute war materials, track freight, plan air raids, organize troop transports, and transfer slave labor. IBM's collaboration was so complete that the Reich actually became dependent of the Hollerith tabulators.[45]

Most disconcerting is the fact that Thomas Watson, architect of the IBM empire, apparently had no moral qualms about dealing with the Third Reich. There is little question, since the recent release of IBM World War II documents, that Watson was aware of how his company's equipment was being used; he visited Germany more than a dozen times and had close contact with Nazi officials, including meetings with Adolf Hitler. In fact, upon returning from one trip, he lectured his employees: "You know, you can cooperate with a man without believing in everything he says and does. If you do not agree with everything he does, cooperate with him in the things you do believe in. Others will cooperate with him in the things they believe in."[41] Thomas Watson, Jr., who succeeded his father at the IBM helm, rationalized his father's involvement by stating, "Dad's optimism blinded him to what was going on in Germany."[47] Watson's chief concerns were the expansion of his empire and bank account. As Black wryly notes, "It was always about the money. As far as IBM was concerned, 'business' was its middle name."[44]

Aftermath

What happened to these engineers and companies when the extent of their complicity was revealed at war's end? In Germany, 24 Farben directors and engineers were indicted in 1947 and tried in the sixth war crimes trial at Nuremberg. Claiming ignorance, most were acquitted of all wrong-doing, despite the fact that some of these executives had visited Auschwitz, witnessed the deplorable conditions at Monowitz, and knew that their workers were renovating existing gassing facilities at Birkenau to accommodate the use of Zyklon B. The court was unconvinced, however, that they were aware that their insecticide was used on humans.[22] Nine were found guilty on the charge of "plunder and spoilation," and four were deemed guilty of using slave labor. Sentences ranged from 1½ to 8 years in prison, but all were released within 4 months.[17]

Topf fared less well. Chief executive Ludwig Topf committed suicide in 1945, and the three engineers were captured by the Russians and interrogated in Moscow. Head engineer Kurt Prüfer was arrested, tried, and sentenced to 25 years imprisonment in a Soviet gulag. He died in 1952. Fritz Sander died in 1946; Karl Schultze served nearly 10 years of a 25-year sentence and was released in 1955.[26] The Topf firm limped along for decades under East German administration and finally declared bankruptcy in 1996.[48] Neither Topf executives nor engineers ever acknowledged responsibility for their part in the Holocaust.

The Ford Motor Company is, of course, still in existence and thriving, despite a number of post-war ethical indiscretions, including the designs of the Pinto and Explorer. In 1938, on his 75th birthday, Henry Ford received the ultimate honor reserved for non-German nationals: the Grand Service Cross of the Supreme Order of the German Eagle, accompanied by a parchment citation praising Ford's accomplishments and signed by Adolf Hitler.[30] One year earlier, another US business giant received the same award in Berlin: Thomas Watson of IBM.[41]

Ford died from cerebral hemorrhage in 1947. An antisemite to the end, on his deathbed he purportedly declared to a newsman, "I'll take my factory down brick by brick before I'll let any of the Jew speculators get stock in the company."[28] Son Edsel, to his credit, resigned a position on the board of directors of American I. G. when the company's complicity became apparent.[16]

IBM continued its dominance of the data processing market and branched into computers. Upon release of Edwin Black's 2001 *IBM and the Holocaust*, which exhaustively documents the firm's involvement, IBM released a self-flagellating and cryptic press release: "IBM and its employees around the world find the atrocities committed by the Nazi regime abhorrent and categorically condemn any actions which aided their unspeakable acts."[49] More recently, the American Computer Scientists Association released a statement of public condemnation, calling for "investigation and criminal prosecution of IBM for engaging in treason during WWII and for acts accessory to mass murder, genocide . . . and various crimes against humanity . . . ."[46]

Pedagogical Suggestions

Integrating Holocaust material into engineering and technology classes takes preparation on the part of the instructor and creativity in designing appropriate class discussions and assignments. Eric Katz's 2006 anthology, *Death by Design: Science, Technology, and Engineering in Nazi Germany*,[50] offers useful readings in a number of areas, including technology, architecture, medicine, biology, and business. It is clear that the fusion of engineering, business, and the military, when coupled with Nazi ideology, resulted in a noxious brew, leading to the deaths of some 11 million individuals.

The exercises described below will allow students a brief immersion.

Professionalism

Had the entire professional class of Germany rebelled against Nazi ideology, the Holocaust would not have happened: judges would not have enforced the extreme restrictions of Nazi law, such as sentencing Jews to death for hoarding too many eggs or owning radios; teachers would not have banished Jewish students from their classrooms, leaving thousands of children to fend for themselves; and engineers would not have designed the mechanisms and infrastructure that allowed the Holocaust to occur.

Having students discuss the nature of professionalism is a useful exercise. Looking at the "why" aspect is especially important, and an instructor can start by asking students to examine why they chose engineering as a career and how they might react as a professional in a country that, over the course of a decade, experiences incremental shifts in political ideology. What my students discovered is unsettling: that the Holocaust simply could not have happened without the complicity of the engineering community. This exercise requires that student reflect not only on the nature of their chosen profession but also to look deeply within themselves, to identify that emotional detachment element that allowed mechanical engineers to design crematoria ovens and civil engineers to design structures such as gassing chambers—all done, apparently, without connecting those items to people.

Codes

At some point in a typical engineering curriculum, students examine their professional codes. They discover that being an engineer entails a rather significant responsibility to the rest of us, encapsulated in the phrase "provide a service to society."

Having students examine older codes is enlightening, as they focus on loyalty to employers and clients; the general public is not mentioned. In fact, the societal service concept is a direct result of the Holocaust: in 1947, most professional codes underwent major revision to build in a moral liability designed to avoid a reiteration of the horrors of the Holocaust. Medical codes, for example, now contain the informed consent provision to avert the possibility of human experimentation. Engineering codes include the service to society provision to focus on the use of engineering skills to enhance the lot of humanity.[51]

Values and Technology

The Holocaust, as well as scientific ventures such as the Manhattan Project, questions the issue of morally neutral technology. The general argument suggests that it's not the device that's responsible, but how it is used; recast in a Holocaust context, the argument becomes "the technology is not evil, but the people who use it are." In contemporary parlance, this is the "guns don't kill people, people kill people" slogan so energetically advanced by organizations such as the National Rifle Association.

It is an important issue to discuss with students who will be actively developing and using technology. A useful starting point is Langdon Winner's *Whale and the Reactor* (1986), which presents the argument that artifacts do indeed embody politics and cultural values, "specific forms of power and authority."[52] Examining the role of IBM through this prism reveals a company that, instead of asking the question "should it be done," focused instead on the issue of "could it be done."[53] According to Jesse Dillard, "The machine embodies the rational translation of an intention, through the application of technology, into physical reality and in turn provides the means for translating ideas into social reality."[53] Ultimately, the question becomes, "What kind of reality do we want?" Our students will be responsible for creating it.

Focusing on means—the technical problem solving—rather than ends—the actual use—is a temptation for the engineer; however, when designers lose track of how their products are used, essentially good people can end up doing some very bad things, as the Holocaust illustrates. Eric Katz, in his excellent article "On the Neutrality of Technology: The Holocaust Death Camps as a Counterexample," flatly states: "No human creation is morally neutral or value-free because all are the products of a particular culture or worldview."[50] The creator cannot escape the creation: Victor Frankenstein is forever linked to his monster and I. G. Farben to Zyklon B. What kinds of products will our students be linked to?

Conclusions

This paper has offered a snapshot of engineering complicity during the Holocaust, ranging from an examination of individual engineers to exploring the role of German and American businesses in what is undoubtedly the most heinous act of the twentieth century—perhaps of all history—the orchestrated and systematic annihilation of millions of people whose only crime was to be born not Aryan.

Lest we forget, however, and relegate those actions to the annals of history or a unique blip on the political landscape, notable contemporary incidents, albeit on a much smaller scale, also illustrate corporate blindness to the human condition:

- In 1984, Union Carbide's pesticide plant, built in the middle of the teeming Indian city of Bhopal, released a gas that killed over 4,000 people outright; people are still dying from the effects, an estimated 15,000 and counting.

- In 1986, W. R. Grace was responsible illegally dumping chemicals from a tanning plant, resulting in the tragic deaths of children in the tiny community of Woburn, Massachusetts. In Libby, Montana, hundreds of mine workers have died from a Grace vermiculite mining venture that contaminated the town and surrounding areas with asbestos fibers.

Hundreds of thousands of lawsuits have been filed against these companies, yet they steadfastly avoid accepting responsibility for their roles in the obvious endangerment of public safety and health. How are these scenarios different, in substance, than what happened during the Holocaust? Where is the "service to society" in raining down gas or asbestos onto unsuspecting communities?

"Hold paramount," the engineering codes state: "Hold paramount the public safety, health, and welfare." What happened in Germany during the alternate reality created by the Nazi regime stands as testament to the perils of ignoring that dictum.

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Maturing of a Multidisciplinary Cohort of STEM Scholars: Year Three

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Abstract

This work addresses the third-year efforts of Colorado State University-Pueblo faculty in retaining a cohort of low-income students majoring in science, technology, engineering, or mathematics (STEM). Originally, 20 in-state freshmen with demonstrated financial need and sufficiently high GPAs (3.0) were awarded four-year scholarships. This work analyzes the third-year activities of re-building, sustaining, and nurturing the cohort of about 20 scholars consisting of mechatronics, civil engineering technology, computer information systems, physics, biology, chemistry, and mathematics students. When compared with the previous year, results show a significant improvement in retention. Mentoring needs and activities increased while tutoring needs ended. Some cohort members started undergraduate research projects with their mentors while some others became involved in engineering design projects and competitions. Through an aggressive student placement program and two career fairs, some cohort students were able to secure internships.

Introduction

To battle high attrition rates, a large number of universities and colleges in the U.S. have adopted learning communities[1] in various forms, from fully integrated curricula for the first year students[2, 3], to material integration within linked courses[4-6]. Since the highest attrition rates occur in the first college year most learning communities focus on the first-year cohorts. A learning community is "a broad structural innovation that can address a variety of issues from student retention to curriculum coherence, from faculty vitality to building a greater sense of community within our colleges[1]." Learning communities help students learn. In addition, they are more sustainable than many other educational reforms[7].

High attrition rates are even more pronounced among low-income, first-generation college students. Engle and Tinto[8] address barriers to college success for low-income students. They claim that "After six years, only 11 percent of low-income, first-generation students had earned bachelor's degrees compared to 55 percent of their more advantaged peers." Some of their recommendations include additional financial aid to students and cohort development. Engstrom and Tinto[9] show that the learning community model improves the persistence of low-income and/or first generation students to stay in college and graduate. Statistics for science, technology, engineering, and mathematics (STEM), low-income, first generation college students have not been compiled, but it stands to reason that due to the demanding nature of STEM programs the attrition data would be even more alarming.

The learning community composed of a cohort from various STEM majors has been described in our earlier work[10]. After a two-year study of the cohort, it was observed that the cohort itself was changing. New students were added while others were replaced, as indicated in Table 1. Furthermore, students are maturing, thus the educational needs of the cohort are changing as well. While the tutoring needs are declining, career-oriented activities are becoming more valued. For example, presentations by professionals from broad STEM areas are successful in reinforcing learning communities. To further immerse students in their disciplines, there is a need for undergraduate research.

In this work, data are presented about a series of activities designed to re-build, sustain, and nurture a third year cohort of about twenty scholars in mechatronics, civil engineering technology, computer information systems, physics, biology, chemistry, and mathematics.

The Multidisciplinary Cohort

Initially, the cohort was established from first-year STEM students with GPAs of 3.0 or higher, and determined financial need. Currently, the Scholarships for STEM Students (S-STEM) program is in its third year of implementation, having scholars that are now in their junior year. The number of students per program is shown in Table 1. Also, the number of cohort students who remained from the first semester is shown in row “Original Cohort Students,” while the retention rate is shown semester by semester (with respect to the original number of students in the cohort) in row “Original Cohort Retention.” The first-year retention rate of 45% is in a sharp contrast with the overall University retention rate of about 60% (Table 2.). However, this fact is not surprising when compared with the data from Engle and Tinto[8].

Table 1. S-STEM Cohort: Number of Students by Major

Major	Semester 1	Semester 2	Semester 3	Semester 4	Semester 5
Biology	6	6	5	6	5
Civil Engineering Technology	2	2	2	2	2
Chemistry	4	4	5	5	4
Computer Information Systems	2	2	4	4	4
Engineering - Mechatronics	4	4	3	4	3
Industrial Engineering	1	1	0	0	0
Mathematics	1	1	1	1	1
Physics	0	0	1	1	1
Total	20	20	21	23	20
Original Cohort Students	20	20	9	7	7
Original Cohort Retention	100%	100%	45%	35%	35%

To analyze the retention rate of the cohort within the context of the University, a set of retention rates from various STEM disciplines has been provided in Table 2. The table shows the first-year retention rates and five-year graduation rates for first-time college students finishing in Spring 2007 and Spring 2008 (accepted in Fall 2002 and Fall 2003) with a declared major in one of the participating STEM disciplines. The engineering-mechatronics program did not exist during the times under consideration (started in 2005), therefore, only one-year-retention rate is included. The total five-year graduation rate of 22.98% represents a decrease from 25.66%, when the data for Table 2 were compiled three years ago. When results for engineering and technology disciplines (CET, CIS, and IE) are considered, the first-year retention rate is 50%, and the five-year graduation rate is about 18%, which are lower than the retention/graduation rates for science and mathematics.

Table 2. Total One-year Retention and Five-Year Graduation Rates for Spring '07 and Spring '08 for First-time College Students in STEM Disciplines

Major	# Students	# Retained	1-Yr. Rate	# 5-Yr. Grads	5-Yr. Rate
Biology	115	74	64.35%	29	25.22%
Civil Engineering Technology	13	10	76.92%	1	7.69%
Chemistry	27	20	74.07%	4	14.81%
Computer Information Systems	55	29	52.73%	13	23.64%
Engineering- Mechatronics	20	10	50%	na	na
Industrial Engineering	20	5	25%	2	10%
Mathematics	9	6	66.67%	2	22.22%
Physics	4	4	100%	1	25%
Total	**263**	**158**	**60.08%**	**52**	**22.98%**

Research and Education Activities

The primary activities of the project in the third year (similar to the previous year) were: a) recruiting and scholar selection/retention, b) awarding of scholarship funds, c) the continuation of the tutoring program for scholars, d) the organization of the mentoring program, e) organization of STEM related presentations, f) call for participation in research during the Nanotechnology Mini-Symposium presentations, and g) the continuation of the assessment activities. To involve the cohort students in undergraduate research, permission was obtained from NSF to use some of the NSF funds that were originally allocated for tutoring to support student projects.

Recruiting and Retention

The primary recruiting activity was the identification of qualifying scholars at the third-year level to strengthen the cohort. Applications were solicited directly from STEM program contacts (mostly department chairs and program coordinators). Each program contact was asked to bring a list of eligible students to the first meeting of the S-STEM Project Management Team in Fall 2009.

The number of awarded S-STEM scholarships was 23 for Spring 2009 and 20 for Fall 2009. Between the two semesters, one S-STEM scholar left the University, one scholar did not show satisfactory progress towards the degree, and three scholars' GPAs fell below the minimum (2.8). New scholarships were awarded to two, third-year students. A scholarship history by major is shown in Table 1.

Cohort Events

There were five major S-STEM events organized in 2009: The Nanotechnology Mini-Symposium with three presentations, a semi-annual Career Fair (Spring and Fall), "The Ropes Course," and "The Fifth Annual Science and Mathematics Student Research Symposium." In addition, S-STEM scholars were encouraged to visit the career center as well as to attend a series of presentations by Biology/Chemistry professors.

Surveys of scholarship recipients dealing with mandatory meetings and the event topics were administered and analyzed. The four point Likert scale was used (strongly agree - SA, agree - A, disagree – D, and strongly disagree – SD). The survey questions were the same as in the second half of the previous year:

1. How interesting was the topic?
2. How relevant was the event to your interests?
3. Was the event helpful in cohort building?
4. Overall, how beneficial was the event to you?

Comments:

The Ropes Course

The Ropes Course is a four-hour, team-building course:

> "designed to benefit groups of all kinds who want to work together toward a common goal. The course objectives are to promote cooperation and group problem-solving skills, as well as, develop individual self-confidence, leadership skills, teamwork, and communication skills. The course introduces groups to artificial stressors and challenges in a controlled and safe environment. The challenge course setting provides an opportunity for groups and individuals to learn about themselves and address personal, interpersonal, and organizational issues. Each team member brings a unique personality and style of communication that contributes to the dynamics of a team. Team members discover how vital individual contributions are to the success of the team. Participants have an opportunity to reflect on their team-building adventure and apply their experience to everyday life[11]."

S-STEM scholars took the Ropes Course on Saturday, April 11, 2009 as a part of their cohort-building activities. Reluctant at the beginning, they all benefited from the course and enjoyed the experience.

Survey Results. All respondents found the event interesting, beneficial and helpful in cohort building. Most found the event relevant. All comments were positive such as "It was fun, challenging, and educational. [This was] a good break from regular coursework." The results of the survey are presented in Table 3.

Table 3. Survey Results for the Ropes Course, 12 Responses

Question	SA	A	D	SD
How interesting was the topic?	8	4		
How relevant was the event to your interests?	5	4	3	
Was the event helpful in cohort building?	10	2		
Overall, how beneficial was the event to you?	5	7		

Nanotechnology Mini-Symposium

The 2009 Nanotechnology Mini-Symposium was held on April 17, 2009, and it included three research presentations from CSU-Pueblo faculty. The faculty presenting were professors from engineering, biology, and chemistry. Apart from their current and past research, all the presenters described at least one project in which they could involve undergraduate students. The following were the symposium presentations: N. Jaksic, "Nanotechnology Education and Research in the Department of Engineering," J. Smith, "Patch Clamp analysis of Whole Cell to Single Molecule Function," and R. Farrer, "Introduction of a Third Dimension in Micro/Nanoscopic Circuitry." Each presentation was at least 45 minutes long.

Survey Results. The Nanotechnology Mini-Symposium was a successful event. All respondents found the event interesting and overall beneficial. Except for one, all respondents found the event also relevant and helpful in cohort building. All comments were positive like "Awesome! More symposiums would be very welcome in the future." Fourteen students responded to the survey. The results are shown in Table 4.

Table 4. Survey Results for the Nanotechnology Mini-Symposium, 14 Responses

Question	SA	A	D	SD
How interesting was the topic?	10	4		
How relevant was the event to your interests?	9	4	1	
Was the event helpful in cohort building?	5	8	1	
Overall, how beneficial was the event to you?	10	4		

Career Fairs

The Career Fair (Spring and Fall semester) is a mandatory event for all S-STEM students. At the event, students are encouraged to visit various employers' booths. However, this year, the event was not greatly appreciated by students since there were not many jobs in sciences and/or engineering/technology. Also, as a part of their mandatory activities, S-STEM scholars are required to visit the University Career Center. Eight S-STEM scholars used Career Services for resumes, cover letters, internship/job searches and career explorations. As a result, three S-STEM scholars were able to obtain internships from industry.

Survey Results. The two career fairs were mandatory S-STEM events, however, they seemed to be less successful this year. The majority of scholars thought that the events were interesting, relevant, overall beneficial, and helpful in cohort building. However, the comments were less encouraging. Comments like "It seems like most of the businesses were looking for business majors to jump into managerial positions," or "Very few science jobs available in area," dominated. Given the current economic situation, the comments reflected the quality of these events. Fifteen students responded to the survey. The survey results are reported in Table 5.

Table 5. Survey Results for two Career Fairs, 15 Responses

Question	SA	A	D	SD
How interesting was the topic?	4	8	2	1
How relevant was the event to your interests?	4	6	3	2
Was the event helpful in cohort building?	3	5	6	1
Overall, how beneficial was the event to you?	5	5	5	

Science and Mathematics Student Research Symposium

The Fifth Annual Science and Mathematics Student Research Symposium held on October 23, 2009, was a three-hour event. It included a poster session, individual student presentations, and a guest speaker session. At the minimum, S-STEM scholars had to visit the posters. Other activities were optional. Also, three S-STEM scholars participated by presenting their posters. Figure 1 shows an S-STEM scholar at the symposium in front of his poster.

Survey Results. The Fifth Annual Science and Mathematics Student Research Symposium was a successful event for S-STEM scholars. All students found the event interesting, relevant, and overall beneficial. Most of the students also found the event helpful in cohort building. Sixteen students responded to the survey. The survey results are presented in Table 6.

Table 6. Survey Results for the Science and Mathematics Student Research Symposium, 16 Responses

Question	SA	A	D	SD
How interesting was the topic?	13	3		
How relevant was the event to your interests?	11	5		

Was the event helpful in cohort building?	7	6		
Overall, how beneficial was the event to you?	9	7		

In summary, all events presented positive learning experiences for S-STEM scholars. Both the cohort-building course and the two research-oriented events were enthusiastically welcomed by the students. Career fairs were not appreciated as much since there were almost no positions in STEM disciplines.

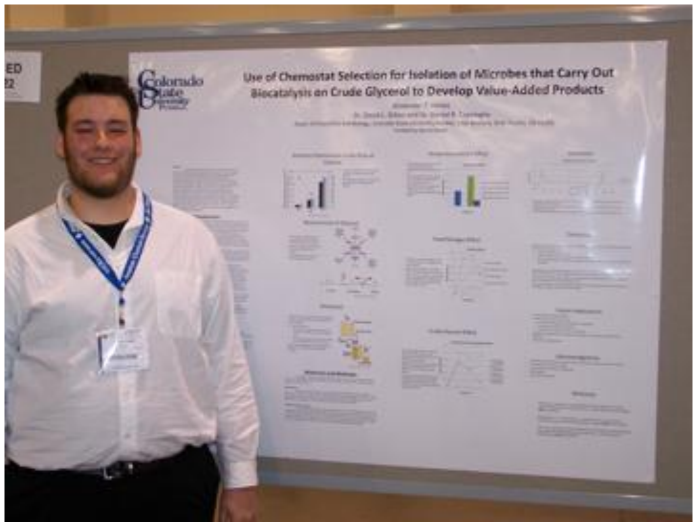

Figure 1. S-STEM Scholar in front of his Poster at the Science and Mathematics Student Research Symposium

Tutoring and Mentoring Activities

Math and physics tutoring was available through the Math Learning Center at CSU-Pueblo. Tutoring in engineering subjects was available in the Engineering department. The CIS program provided its own tutors for all their students. To serve the whole S-STEM cohort, a graduate student was given an office space and was scheduled two to four hours per day to perform event and meeting scheduling, tutoring, and administrative duties dealing with the S-STEM grant. While the tutoring function was advertised to all S-STEM students, again, there was no demand for this activity. This result was anticipated by the S-STEM Project Management Team.

Most of the mentoring activities dealt with undergraduate research and special design projects. In chemistry, two students attended conferences and presented their findings. One student was a co-author on two papers:

1. Kinney, C. A., Furlong, E. T., Kolpin, D. W., Bemis, D. W.* (S-STEM scholar), Kelly, C., Hay, A., Zaugg, S. D., “Biosolids and earthworms: Bioaccumulation, toxicity, and removal

of anthropogenic organic contaminants," 2009 Fall American Chemical Society National Meeting, August 16-20. Washington, D.C.

2. Bemis, D. W.* (S-STEM scholar), Kinney, C. A., Brownawell, B., Kelly, C., Furlong, E.T., Kolpin, D. W., Zaugg, S. D., "Mitigation of Anthropogenic Organic Contaminants using Vermiculture," 2009 Fall American Chemical Society National Meeting, August 16-20. Washington, D.C.

During the aforementioned Fifth Annual Science and Mathematics Student Research Symposium held on October 23, 2009, three S-STEM scholars (from biology and chemistry) presented the following posters:

1. Alexander T. Hynes* (S-STEM scholar), Bradley Mohar, Daniel Caprioglio, David L. Dillon , "Use of Chemostate Selection for Isolation of Microbes for Biocatalysis of Crude Glycerol to Value-Added Products."
2. Daniel Lee*, Sarah N. Deffit* (S-STEM scholar), Daniel Caprioglio, and Sandra J. Bonetti , "The Optimization and Isolation of Cellulase Enzymes from Penicillium."
3. Kinney, C. A., Furlong, E. T., Kolpin, D. W., Bemis, D. W.* (S-STEM scholar), Kelly, C., Hay, A., Zaugg, S. D., "Biosolids and earthworms: Bioaccumulation, toxicity, and removal of anthropogenic organic contaminants."

In engineering, three S-STEM scholars participated in a regional robotics competition organized by the American Society of Mechanical Engineers (ASME). Also, one of these three scholars was involved in an Institute of Electrical and Electronics Engineers (IEEE) Regional Robotics Competition. S-STEM students, as parts of their respective teams, placed in the finals of both competitions. Figure 2 depicts the student robot for the ASME competition which successfully negotiated an obstacle. Figure 3 shows final student preparations for the IEEE Regional Robotics Competition in front of the audience consisting of preschool children from the local day care facility.

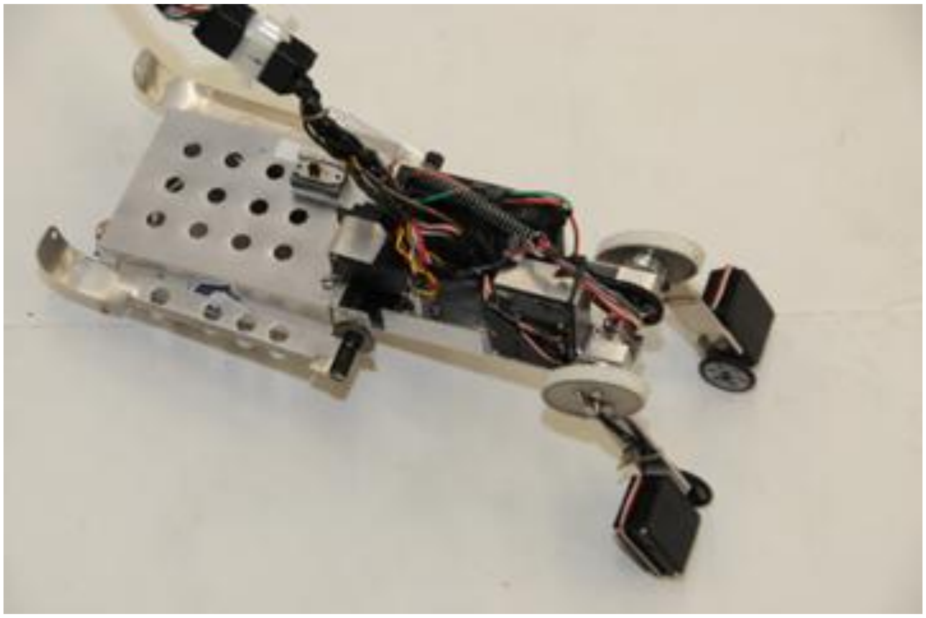

Figure 2. Robot for the 2009 ASME Robotics Competition

Figure 3. Students Preparing their Robots for the 2009 IEEE Regional Robotics Competition in Front of Preschool Children from a Local Day Care Center

Conclusion

This work analyzes the third-year activities of building, sustaining, and nurturing a cohort of about twenty scholars consisting of mechatronics, civil engineering technology, computer information systems, physics, biology, chemistry, and mathematics students at Colorado State University - Pueblo. The results show a significant improvement in retention when compared to the previous year. Mentoring needs and activities increased while tutoring needs ended. Maturing of the cohort is evidenced by students' undergraduate research, publications, and presentations as well as with their involvement in engineering design projects and competitions. Through an aggressive student placement program and two career fairs, three cohort students were also able to secure internships. It is our hope that all of the current S-STEM scholars will finish their degrees next year.

Acknowledgment

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Improving the Participation and Retention of Minority Students in Science and Engineering Through Summer Enrichment Programs

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Abstract

Although many California Community College students enter college with high levels of interest in science and engineering, their levels of preparation for college-level work, especially in math and engineering, are so low that the majority of them drop out or change majors even before taking transfer-level courses. In 2008, Cañada College, a Hispanic-Serving community college in Redwood City, CA, was awarded a Minority Science and Engineering Improvement Program (MSEIP) grant by the US Department of Education to develop and implement a project that aims to maximize the likelihood of success among underrepresented and educationally disadvantaged students interested in pursuing careers in STEM fields. The project, entitled Student On-ramp Leading to Engineering and Sciences (SOLES), incorporates strategies that address challenges and barriers to recruitment, retention and success of minority students. Among the strategies developed for this project are two summer programs that were implemented for the first time in summer 2009. The Summer Math Jam is a two-week intensive mathematics program designed to improve student preparation for college-level math courses. The Summer Engineering Institute is a two-week residential summer camp that offers participating students the opportunity to gain insight into the engineering academic program through a combination of lectures, hands-on laboratory activities, workshops and projects with engineering professionals. Preliminary results indicate success of both programs. Math Jam participants show improvement in the Math Placement test. Almost all participants scored higher in the placement test compared to their pre-program scores. For sixty four percent of them, the improvement in their scores was high enough to place them to at least the next higher math class. Engineering Institute participants showed improved understanding of the engineering profession and the engineering educational system. Participants from both programs also expressed positive overall attitude and opinions of the program objectives, content, activities and implementation.

1. Introduction

Community colleges serve as the gateway to higher education for large numbers of students in the U.S., especially minority and low-income students. Yet for many students, the community college gateway does not lead to success. Only one in four students wanting to transfer or earn a degree/certificate did so within six years, according to a recent study of California community colleges[1]. African American and Hispanic students have even lower rates of completion. According to the study, only 15% of African American students and 18% of Latino students completed a degree or certificate within six years, compared to 27% of Caucasian students, and 33% of Asian students.

For Science, Technology, Engineering, and Math (STEM) fields, lower success and retention rates for minority students are observed at both community college and university levels resulting in underrepresentation of minority groups in these professions. For instance, while comprising almost 25% of the U.S. population, African Americans and Latinos make up less than 7% of the individuals with B.S. or higher-degrees in the science and engineering fields[2]. Strategies that have been proven effective in increasing the retention and success of minority students in science and engineering include mentoring programs[3,4], introducing context in introductory courses[5], alternative instructional strategies such as collaborative and interactive learning[6], summer bridge programs[7,8], and academic support services such as tutoring, Academic Excellence Workshops (AEWs), and peer mentoring[9].

In 2008, Cañada College, a Hispanic-Serving community college in Redwood City, CA, was awarded a Minority Science and Engineering Improvement Program (MSEIP) grant by the US Department of Education. The project, entitled Student On-ramp Leading to Engineering and Sciences (SOLES), aims to maximize the likelihood of success among underrepresented and educationally disadvantaged students interested in pursuing careers in STEM fields by incorporating strategies that address challenges and barriers to recruitment, retention and success of these students. Among the strategies developed for this project are two summer programs that were implemented for the first time in summer 2009. The Summer Math Jam is a two-week intensive mathematics program designed to improve students' preparation for college-level math courses. The Summer Engineering Institute is a two-week residential summer camp that offers participating students the opportunity to gain insight into the engineering academic program through a combination of lectures, hands-on laboratory activities, workshops and projects with engineering professionals. This paper summarizes the results of the first year of implementation of these two summer programs.

2. The Summer Math Jam

2.1 Program Goals

Although nationally, interest in science and engineering is lower for Latino, African American, and Native American students compared to other ethnic groups[2], this is not the case at Cañada College.

Table 1 on the next page summarizes the ethnic distribution of students who took the math placement test from April 2006 to May 2008 at Cañada College. Table 2 summarizes the ethnic distribution of students taking the placement test, students declaring an engineering major and students who transferred to a four-year school as an engineering major (2005-2007) for the four largest ethnic groups – Mexican Americans, Caucasian Americans, Asian Americans, and African Americans. Although Mexican Americans represent only 35.5% of all the students who took the placement test, they represent 50.9% of students who declared engineering as their major. Despite such a high interest in engineering among Mexican Americans, they represented only 19.0% of all students who transferred to a four-year school as engineering majors from 2005-2007. These data clearly represent a much lower rate of retention and transfer for both Mexican Americans and African Americans compared to Caucasian Americans and Asian Americans.

Table 1. Ethnicity distribution of students who took the Math placement test from April 2006 to May 2008.

Ethnic Background	No of students	% of Total
African American	171	5.8%
American Indian Alaskan Native	16	0.5%
Asian American	175	5.9%
Caucasian American	950	32.0%
Filipino	92	3.1%
Mexican American	1055	35.5%
Other Hispanic	135	4.5%
Other	241	8.1%
No Response	135	4.5%
Total	2970	100.0%

Table 2. Summary of ethnic distribution of students who took the placement test, who declared STEM majors, who Engineering major and students who transferred to a four-year school as Engineering major (2005-2007) for the four largest ethnic groups.

Percentage of Students Who:	Mexican Americans	Caucasian American	Asian Americans	African Americans	Others
Took the Math placement Test	35.5%	32.0%	5.9%	5.8%	26.6%
Declared majors in Engineering	50.9%	25.4%	3.5%	1.6%	20.2%
Transferred as Engineering majors	19.0%	19.0%	28.6	33.3%	33.3%

The inadequate preparation of minority students entering Cañada College is apparent from the results of the math placement tests. Table 3 summarizes the placement test results for students who declared engineering as their major. Mexican American and African American students have the lowest percentages of students placing into Trigonometry, and the highest percentages of students placing into Pre-algebra. The results of these math placement tests have serious and adverse consequences for these students' timely completion of lower-division courses in science and engineering, and subsequent transfer to a university.

Table 3. Ethnic distribution of Math Placement test results for students who declared majors in Engineering (Data from April 2006-May 2008; 114 students)

Ethnic Group	Pre-algebra	Algebra	College Algebra	Trig	% of Total
African American	50.0%	0.0%	50.0%	0.0%	5.3%
Asian American	16.7%	0.0%	16.7%	66.7%	5.3%
Caucasian American	17.2%	17.2%	48.3%	17.2%	25.4%
Mexican American	31.0%	24.1%	34.5%	10.3%	50.9%
Other Hispanic	16.7%	0.0%	33.3%	50.0%	5.3%
Other	33.3%	66.7%	0.0%	0.0%	2.6%
No Response	0.0%	33.3%	0.0%	66.7%	5.3%
% of Total	25.4%	20.2%	35.1%	19.3%	100.0%

Engineering majors require two years of courses that include sequences of courses in calculus and physics. A student who starts at College Algebra has an additional one and a half years of mathematics (College Algebra, Trigonometry and Pre-calculus) on top of the two-year sequence of lower-division transferable courses. A student who starts at Pre-algebra has an additional two and a half years (Pre-algebra, Algebra, College Algebra, Trigonometry and Pre-calculus) of mathematics before they are ready to take Calculus. Hence, for Mexican American students at Cañada who want to major in engineering, 34.5% of them would need at least three and a half years, 24.1% would need at least four years, and 31% of them would need at least four and a half years in a community college before they can even transfer to a four-year university. Half of the African American students will need at least three years, while the other half would need at least four years at a community college before transferring. For many of them with family obligations and no family support, this is simply too long of a career path.

The Summer Math Jam at Cañada College was developed to help these students who have expressed interest in pursuing engineering and other STEM majors but placed low in the sequence of math courses.

The Summer 2009 Math Jam was developed with the following program goals:

1. Help students progress faster through Cañada's math sequence to enable them to transfer to a 4 year university earlier or to complete an associate's degree earlier.
2. Recruit as many students as possible into STEM majors.
3. Increase students' awareness of the tools, skills, and resources they need to be successful college students.
4. Develop a community of learners among program participants.

Appendix A shows a summary of the two-week schedule of the program that was run from June 8 to June 19, 2009. This two-week period was selected to coincide with Cañada College's break between the end of spring 2009 semester and the beginning of the summer 2009 session.

Morning sessions were mostly devoted to studying math either in groups or individually using MyMathTest[10], an online system developed by Pearson Education for developing math placement tests and short math refresher programs. Note that the first week of the program had more workshops related to resources and skills needed for college success. Many of the workshops planned for the second week were either cancelled or made optional as a result of a mid-program focus group that indicated that students wanted to devote more time to studying math, and less on these workshops.

2.2 Profile of 2009 Summer Math Jam Students

The 2009 Summer Math Jam recruited 40 participants, with 34 of them successfully completing the program. Table 4 is a summary of the demographics of the 2009 Summer Math Jam 34 participants who completed the program. The gender distribution of 64.7% female and 35.3% male is very similar to the College's overall gender distribution (63% female, 34% male, and 3% unknown). The biggest ethnic group is Hispanic representing 61.8% of Math Jam students, significantly higher than the College's overall Hispanic student body of 44%. Fifty percent of the students are first in their family to attend college.

Table 4. Demographics of 2009 Math Jam participants.

Demographics	**N**	**%**
Gender		
Female	22	64.7%
Male	12	35.3%
Total	34	
Ethnicity		
Afro-American	2	5.9%
Asian	1	2.9%
Caucasian	7	20.6%
Hispanic	21	61.8%
Other	3	8.8%
Total	34	
First in Family to Attend College?		
Yes	17	50.0%
No	17	50.0%
Total	34	

2.3 Math Jam Results

To evaluate the success of Math Jam in achieving its primary goal of helping students progress more quickly through the sequence of math courses they need before transfer, the Math Test Placement scores of the participants before and after Math Jam are compared. Table 5 summarizes this comparison. Of the 33 students who had pre- and post-Math Jam test scores, 31 (or 93.9%) scored higher after completing Math Jam, one student scored lower, and one student's score did not change. Twenty one out of 33 students (or 63.6%) improved their scores enough to be placed into a higher math course compared to their pre-Math Jam results. These results although not as dramatic as what the program staff was aiming for are slightly better than the 56% "jump rate" for participants of a similar two-week summer program at Pasadena City College[11].

Table 5. Test Placement Results after Math Jam.

Results of Post Math Jam Placement Test	**N**	**%**
Better	31	93.9%
Unchanged	1	3.0%
Worse	1	3.0%
Placed to a Higher Level	21	63.6%

Table 6. Math Jam Student Survey Attitudes.

Attitudes Response Scale: 5 – Strongly Agree, 4 – Agree, 3 – Neutral, 2 – Disagree, 1 – Strongly Disagree.	**Pre-Program**	**Post-Program**	**Difference** (Post - Pre)
I feel (was) excited about participating in Math Jam.	4.12	4.15	0.03
I feel anxious about studying math.	3.65	3.48	-0.17
I have effective math study skills.	2.91	3.48	0.57*
I am confident that I have the necessary skills and academic preparation to be a successful college student.	3.79	4.04	0.24*
I am confident that Canada College is the right college for me.	4.44	4.58	0.14
I am confident that I have selected an appropriate major.	4.21	3.96	-0.24
I felt connected to students, tutors, teachers and staff in Math Jam.	-	4.31	-
It was helpful for me to participate in Math Jam.	-	4.52	-

* The difference is statistically significant ($p < 0.050$).

Table 6 summarizes the result of the pre- and post-program student survey designed to evaluate the success of Math Jam in achieving its secondary goals of increasing student awareness of tools, skills and resources needed to succeed in college. The survey evaluated student attitudes towards the program, their selected major, and Cañada College as their selected school, as well as their perceptions of their level of preparation for college-level work before and after Math Jam. Results of the survey show that Math Jam maintained student enthusiasm for the program, reduced (slightly although not statistically significant) math anxiety, improved student math study skills (statistically significant), and academic preparation for college success. The program was not successful in helping students select an appropriate major as indicated by a slight drop in the students' level of confidence regarding their selected major. The program was successful in building a sense of community among the participants and staff.

Table 7 summarizes the results of survey of students' opinion of their knowledge and skills needed for college success. Statistically significant improvements in awareness of education planning, math anxiety, learning styles, financial aid and scholarships, and the MyMathTest software were achieved. The most significant gain is on the use of MyMathTest software, and this is no surprise considering that the focus of the program is on studying math using this tool. The measured increase in student awareness of the transfer process and exploring majors, time management, students' personal strengths, and the use of calculators for a math class were not statistically significant. There is a slight decrease (although not statistically significant) in student perceived knowledge of essay writing. It should be noted that due to student demand for more time spent on studying math, the Math Jam staff decided to cancel some workshops, and make others optional.

Table 7. Math Jam Student Survey: knowledge and skills important for college success.

Knowledge and Skills for College Success Response Scale: 4 – A Lot, 3 – Quite a Bit, 2 – Some, 1 – A little, 0 – Nothing.	**Pre-Program**	**Post-Program**	**Difference** (Post - Pre)
Time management	3.24	3.52	0.28
Education planning	3.18	4.07	0.89**
Math anxiety	3.09	3.70	0.62*
Your learning style	3.41	3.96	0.55*
Your personal strengths	3.62	3.74	0.12
Financial aid and scholarships	2.76	3.78	1.01**
Essay writing	3.18	2.85	-0.32
How to transfer and explore majors	2.84	3.30	0.46
How to use a calculator for a math class	3.18	3.22	0.04
MyMathTest Software	2.50	4.30	1.80**

* The difference is statistically significant ($p < 0.050$).
** The difference is statistically significant ($p < 0.001$).

On the areas of college resources and support services, statistically significant gains were measured in student awareness of the Learning Center, Tutorial Services, Financial Aid Office, Transfer Center, TRIO and MESA as shown in Table 8. The measured gains in student awareness of the Library, Health Center, Psychological Services, Disabled Student Services, and EOPS were not statistically significant due to the need to have workshops related to these areas either be canceled or made optional in order to allot more math study time.

Table 8. Math Jam Student Survey: Knowledge of College Resources and Support Services.

Knowledge of Resources and Support Services Response Scale: 4 – A Lot, 3 – Quite a Bit, 2 – Some, 1 – A little, 0 – Nothing.	**Pre-Program**	**Post-Program**	**Difference** (Post - Pre)
Library	2.94	3.52	0.58
Learning Center	3.21	4.48	1.27**
Health Center	1.97	2.15	0.18
Psychological Services	1.73	2.08	0.35
Tutorial Services	2.79	4.19	1.40**
Financial Aid Office	2.82	3.96	1.14**
Transfer Center	2.06	2.70	0.64*
Disabled Student Services	1.41	1.81	0.41
TRIO	2.30	3.07	0.77*
EOPS	2.64	3.22	0.59
MESA	2.21	4.07	1.86**

* The difference is statistically significant ($p < 0.050$).
** The difference is statistically significant ($p < 0.001$).

As a whole, the 2009 Math Jam was successful in achieving most of its goals except those related to recruiting more students into the STEM fields, or helping them select an appropriate major.

3. The Summer Engineering Institute

The Summer Engineering Institute (SEI) is a two-week residential program held on campus at San Francisco State University. The goals of the program are to introduce students to the engineering educational system and the engineering profession, to recruit students into an engineering field, increase student awareness of resources and skills needed for college success, and to increase student knowledge of specific engineering topics. Appendices B-1 and B-2 show a summary of the schedule of the 2009 Summer Engineering Institute that was held from July 19^{th} to July 31^{st}. Mornings were generally devoted to lecture sessions, with group activities and hands-on workshops in the afternoon to reinforce concepts learned from the lectures. Most evenings were devoted to working on group projects.

3.1 Profile of SEI Students

Due to budgetary constraints, the implementation of the 2009 Summer Engineering Institute was done in partnership with the California Department of Transportation (Caltrans). There were 54 participants; 25 were jointly recruited by Cañada College and San Francisco State University, and 29 were recruited by Caltrans. For the purpose of this paper, only the 25 students recruited by Cañada and SFSU are included in the analysis.

Table 9 is a summary of the demographics of the 25 participants that were recruited by Cañada College and San Francisco State. Thirteen of the students were female, and twelve were male. Hispanics constitute the largest ethnic group at 48%, followed by Asians or Pacific Islanders (24%), and African Americans (12%). Forty-four percent were the first in their family to attend college.

Table 9. Demographics of 2009 Summer Engineering Institute.

Demographics	**N**	**%**
Gender		
Female	13	52.0%
Male	12	48.0%
Total	25	
Ethnicity		
African American	3	12.0%
Asian American or Pacific Islander	6	24.0%
Caucasian	2	8.0%
Hispanic	12	48.0%
Other	2	8.0%
Total	25	
First in Family to Attend College?		
Yes	11	44.0%
No	14	56.0%
Total	34	

To evaluate the success of SEI in achieving its goal of recruiting students to major in an engineering field, a pre- and post-survey of students' intended major in college was done. Table 10 on the next page summarizes the results of this survey. At the beginning of the program, 17 out of the 25 students (or 68%) indicated one of the fields of engineering as their intended major, with Engineering (General) as the most popular choice. The remaining 8 out of the 25 students (or 32%) were undecided. After the program, students intended major remained the same except for one student who switched from Civil Engineering to Landscape Architecture. Students who were initially undecided remained undecided. Clearly, the program failed to recruit additional students to major in any of the engineering fields.
Table 10. SEI Student Survey: Intended Major in College.

Major	Pre-SEI		Post-SEI	
	N	%	N	%
Biomedical engineering	1	4.0%	1	4.0%
Civil Engineering	4	16.0%	3	12.0%
Computer engineering	2	8.0%	2	8.0%
Electrical Engineering	0	0.0%	0	0.0%
Engineering (General)	7	28.0%	7	28.0%
Mechanical	3	12.0%	3	12.0%
Undecided	8	32.0%	8	32.0%
Other (Landscape Architecture)	0	0.0%	1	4.0%
Total	25		25	

The failure of the SEI program to achieve its primary goal of recruiting students into engineering is also reflected in Table 11. Although student enthusiasm for the program increased significantly, there was a statistically significant decrease in student confidence that the Institute will help them select an appropriate engineering major. The slight increase in student level of confidence that they have the necessary skills and preparation for college success is not statistically significant.

Table 11. SEI Student Survey: Attitudes.

Attitudes Response Scale: 5 – Strongly Agree, 4 – Agree, 3 – Neutral, 2 – Disagree, 1 – Strongly Disagree.	**Pre-Program**	**Post-Program**	**Difference** (Post - Pre)
I feel excited about participating in Summer Engineering Institute.	4.24	4.58	0.34*
I am confident that I have the skills and academic preparation to be a successful college student.	4.32	4.42	0.10
I am confident that SEI will help me in selecting an appropriate Engineering major.	4.16	3.63	-0.54*

* The difference is statistically significant ($p < 0.050$).

With regards to SEI’s goal of increasing students’ awareness of knowledge and skills that are important for college success, the results of pre- and post-SEI student surveys are summarized in Table 12. All the gains that were measured after the program were statistically significant except in the area of using a calculator for engineering calculations. Pre- and post-SEI average student responses were all between “Quite a Bit” and “A Lot” in all areas except for “How to transfer and explore majors.” This is again an indication that the program was not successful in helping students explore career options, or select an appropriate major.

Table 12. SEI Student Survey: Knowledge and Skills important for College Success.

Knowledge and Skills for College Success Response Scale: 4 – A Lot, 3 – Quite a Bit, 2 – Some, 1 – A little, 0 – Nothing.	**Pre-Program**	**Post-Program**	**Difference** (Post - Pre)
Time management	3.72	3.96	0.24
Education planning	3.80	3.83	0.03
Your learning style	3.60	3.83	0.23
Your personal strengths	3.76	4.00	0.24
Self Confidence	3.92	4.13	0.21
Essay writing	3.36	3.38	0.02
How to transfer and explore majors	2.80	2.92	0.12
Using a calculator for Engineering Calculations	3.04	3.67	0.63*

* The difference is statistically significant ($p < 0.050$).

With regards to its goal of increasing student knowledge of college resources and support services, results of the student surveys are shown in Table 13. There is no statistically significant change in student responses in any of the areas after the completion of SEI.

Table 13. SEI Student Survey: Knowledge of College Resources and Support Services.

Knowledge of Resources and Support Services Response Scale: 4 – A Lot, 3 – Quite a Bit, 2 – Some, 1 – A little, 0 – Nothing.	**Pre-Program**	**Post-Program**	**Difference** (Post - Pre)
Library	3.16	3.50	0.34
Undergraduate Advising	2.56	2.67	0.11
Learning center	2.88	3.17	0.29
Health center	2.60	2.71	0.11
Psychological services	2.20	2.29	0.09
Tutorial services	2.88	2.96	0.08
Financial aid office	3.04	2.75	-0.29
Transfer center	2.32	2.38	0.06
Disabled student services	1.88	1.96	0.08
MESA	2.96	3.08	0.12

Table 14. SEI Student Survey: Knowledge of Specific Engineering Topics.

Knowledge of Specific Engineering Topics Response Scale: 4 – A Lot, 3 – Quite a Bit, 2 – Some, 1 – A little, 0 – Nothing.	**Pre-Program**	**Post-Program**	**Difference** (Post - Pre)
Computer-Aided Design (CAD)	2.28	2.46	0.18
Laboratory Experimental Procedures	2.16	2.67	0.51*
Robotics	2.04	2.79	0.75*
Computer Engineering	2.04	2.92	0.88**
Electronics and Electrical Engineering	2.40	3.29	0.89**
Geotechnical Engineering	1.72	2.83	1.11***
Hydraulics	1.76	2.88	1.12***
Data Analysis	2.24	3.38	1.14***
Operations Analysis	2.04	3.21	1.17***
Bridge Design	2.16	3.38	1.22***
Engineering Design Process	2.20	3.79	1.59***
Surveying and Map Reading	2.20	3.88	1.68***

* The difference is statistically significant ($p < 0.050$).
** The difference is statistically significant ($p < 0.010$).
* **The difference is statistically significant ($p < 0.001$).

The 2009 SEI's main area of success is in increasing student knowledge of specific engineering topics. Table 14 shows that except for Computer-Aided Design (CAD), statistically significant increase in student knowledge of engineering topics covered in the Institute. It should be noted that the 2009 SEI was planned and implemented through collaboration with the California Department of Transportation (Caltrans). As a result, the most significant increases in student knowledge were in subject areas that directly pertain to the expertise of the Caltrans personnel who served as lecturers and project advisors for the participating students.

Although SEI was successful in increasing student knowledge and understanding of specific engineering topics and of the engineering profession, it did not achieve its goal of recruiting additional students to major in engineering. Results of pre- and post-program surveys asking students to rate their confidence that "the Summer Engineering Institute will help in selecting an appropriate Engineering major" show that student confidence level dropped significantly after the program. One possible contributing factor could be the overemphasis given to Civil Engineering and other related fields brought about by the partnership with Caltrans whose personnel have expertise mostly in these fields. However, an investigation on research and literature on career selection, especially those in the STEM fields, indicates that the underlying reason might be beyond the SEI curriculum.

Many researchers believe that career interests and career plans start developing in middle schools, and recommend that career explorations and career planning begin before high school, when students have already made major career decisions in the form of curriculum choices[12,13,14,15,16,17,18]. Many of these middle school and high school students passively eliminate technical career options by not choosing courses that are not needed for these STEM fields[12]. In many cases, students who pursue STEM courses have made these career decisions before they finish high school so that STEM career exploration summer programs before their senior year, or before they start college may be too late.

4. Conclusion

The first year of implementation of the two MSEIP summer programs at Cañada College shows success in achieving some of the programs' goals. Math Jam was successful in achieving its primary goal of helping students progress faster through Cañada's math sequence, with 63.6% of student participants placing to at least the next higher math course. It was also successful in increasing students' awareness of college success tools and skills, and in creating a community of learners that felt comfortable at Cañada. Over the next few semesters, the academic performance of Math Jam participants will be monitored to determine whether the success of the program results in subsequent student academic success. For future implementations of Math Jam, even more emphasis will be given to studying math, and less on college success workshops. Workshops will only focus on topics that are more directly related to math, such as overcoming math anxiety and test taking strategies. Additional workshops on other college success skills and resources will be made available to math jam participants through the College's Learning Resource Center during the academic year.

The Summer Engineering Institute was successful in increasing student knowledge and understanding of specific engineering topics and of the engineering profession. It was also successful in maintaining and even increasing participant excitement about the program. However, increased knowledge of the profession and increased excitement about the summer institute did not necessarily translate to increased interest among participants to pursue engineering as a career. Among students who solidified their choice of an engineering career and decided to major in one of the engineering fields, the program has provided context to their study of engineering – a strategy that has been proven to increase student motivation and persistence[5] – especially as they struggle through the first two years of the engineering curriculum. For future implementations of the Summer Engineering Institute, a more balanced curriculum will be adopted to introduce students to the different fields of engineering through a combination of lectures, laboratory activities, workshops, and design projects. And unlike the previous SEI where all participants worked on the same culminating design project, participants will be given the option to select a project that most closely fits their interests. To better understand the effect of this new curriculum on student career choices, additional assessment plans will be developed, including focus groups and exit interviews of student participants, and follow up studies of both groups of students – those who pursue an engineering major and those who chose to major in a non-engineering field. Finally, the SEI project team will consider developing a curriculum for a summer engineering institute suitable for middle school students to introduce them to the engineering profession before they make major decisions regarding their future careers.

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Appendix A
2009 Math Jam Schedule

Week 1

	June 8	June 9	June 10	June 11	June 12
Time	Monday	Tuesday	Wednesday	Thursday	Friday
9-10 am	Welcome & Ice Breaker	Math Study Skills	Math!	Math!	
10 -12 pm	Placement Test / Review Results	Math!			
12-12:30 pm	Lunch	Lunch	Lunch	Lunch & Mesa Panel	Lunch
12:30-1 pm	Meet the staff & Overview of Math Jam	Math Anxiety Assessment	Financial Aid		Field Trip
1-1:30 pm	Time Management				
1:30-2 pm		Ed Plan Counseling OR Math Anxiety Workshop	Ed Plan Counseling OR Time Management	Learning Styles	
2-2:20 pm	Why an Education Plan?				
2:20-2:30 pm	Signups for Work Sessions				
2:30-3:30 pm [Optional]		Individual Ed Plan Counseling Skills Counseling	Individual Ed Plan Counseling Skills Counseling	Individual Ed Plan Counseling Skills Counseling	

Week 2

	June 15	June 16	June 17	June 18	June 19
Time	Monday	Tuesday	Wednesday	Thursday	Friday
9-10 am	Math!	Math!	Math!	Post-Program Survey	
10 -12 pm				Placement Test	
12-12:30 pm	Lunch	Lunch	Lunch	Lunch & Guest Speaker	Barbecue and Closing Ceremony
12:30-1 pm	LEAP Strengths Quest	Math!	Math!		
1-1:30 pm					
1:30-2 pm				Transfer OR Graphing Calc Workshop	
2-2:30 pm	Math Jam and You				
2:30-3:30 pm [Optional]	Individual Ed Plan Counseling / Skills Counseling	Individual Ed Plan Counseling / Skills Counseling	Individual Ed Plan Counseling / Skills Counseling	Individual Ed Plan Counseling / Skills Counseling	

Appendix B-1
2009 Summer Engineering Institute Schedule: Week 1

	July 19	**July 20**	**July 21**	**July 22**	**July 23**	**July 24**	**July 25**
Time	Sunday	Monday	Tuesday	Wed.	Thursday	Friday	Saturday
7-8 am		Breakfast	Breakfast	Breakfast	Breakfast	Breakfast	
8-9 am		Project Mgmt.	Map Reading	Design 1	Bridge Design	Environ	Breakfast
9-9:30							Personal Time
9:30-10		Operations Analysis 1	Operations Analysis 2	Landscape Architect.	Design 2	Computer Engr 1	
10-11 am							Field Trip 10 AM to 3 PM
11-12:30		Math 1	Surveying	Math 2	Commun 1	Elecrical Engr 1	
12:30-1:30		Lunch	Lunch	Lunch	Lunch	Lunch	
1:30-3		Pre-Program Assess	Guest Speaker	Field Trip Bay Bridge	Activities Exploring Bridges	Commun 2	
3-4 pm	Regist.	Commun. Activity	Blind Obstacle Course			Personal Time	Personal Time
4-5:30	Welcome Ceremony	Interview Students/ Team Building				Group Activity	
5:30-6	Campus Tour		Personal Time		Personal Time		
6-7 pm	Dinner	Dinner	Dinner	Dinner	Dinner	Dinner	Dinner
7-8:30	Group Activity	Project Time	Project Time	Project Time	Project Time	Project Time	Activity / Movie Night
8-9 pm	Project Info						
9-10 pm	Personal Time	Personal Time	Personal Time	Personal Time	Personal Time	Personal Time	
10:30 pm	Lights Out	Lights Out	Lights Out	Lights Out	Lights Out	Lights Out	In Rooms

Appendix B-2
2009 Summer Engineering Institute Schedule: Week 2

	July 26	**July 27**	**July 28**	**July 29**	**July 30**	**July 31**
Time	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
7:00-8:00 am		Breakfast	Breakfast	Breakfast	Breakfast	Breakfast
8:00-8:30 am		Hydraulics	Design 4	Elec. Eng. 2	Project Time	Presentations (HSS-154)
8:30-9:30 am	Breakfast					
9:30-11:00 am	Personal Time	Design 3	Elec. Eng. 2	Comp. Eng.3		
11:00-12:30	BBQ & Fun Games	Comp. Eng. 2	Geo Tech	Commun. 3		
12:30-1:30 pm		Lunch	Lunch	Lunch	Lunch	Closing / Awards Banquet
1:30-2:30 pm		Field Trip	Going Green	Guest Speaker	Mock Presentations	
2:30-3:00 pm				Robotics		
3:00-3:30 pm	Project Time					Checkout time
3:30-5:00 pm			Solar Project			
5:00-6:00 pm		Personal Time	Personal Time	Personal Time	Personal Time	
6:00-7:00 pm	Dinner	Dinner	Dinner	Dinner	Dinner	
7:00-8:00 pm	Communication Activity	Project Time	Project Time	Project Time	Personal Time	
8:00-8:30 pm					Party	
9:00-10:00 pm	Personal Time					
9:30-10:00 pm		Personal Time	Personal Time	Personal Time		
10:30 pm	Lights Out	Lights Out	Lights Out	Lights Out	Lights Out	

Student Recruitment by Faculty Phone-a-Thons

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Abstract

Phone-a-thons are an enrollment effort that began in earnest in the 1980s as a method for recruiting college-bound students. Often, this technique manifests in the employment of current students to staff phone banks and call prospective students during prime time periods. Although enrollment management functions are not part of the traditional faculty role, the authors describe a program of involving faculty from the College of Engineering, Forestry and Natural Sciences in an annual phone-a-thon. Each year since the fall of 2005, faculty have been organized to call students who have submitted an application to study in an engineering, science, mathematics, or forestry major at Northern Arizona University, but have not yet committed to enroll in the university via deposit. The faculty's phone call mission is to reach out to this selective group of prospective students in a nurturing manner in order to exemplify our student-focused environment, to answer questions, and to increase yields. This paper will present summary data with conclusions about the effectiveness of this annual effort, which takes place over the course of two evenings each year.

Introduction

Communication with prospective university students often begins as early as the middle school years with admissions offices beginning dialogues about college entrance requirements and pathways to student success[1]. It is not until the high school years, and in particular, the junior and senior years that telephone recruitment campaigns are used by colleges and universities. A phone-a-thon is one such telemarketing effort. It is best described as "the planned use of the telephone as a recruitment, follow up, and retention medium in conjunction with traditional recruitment programs to increase the yield rate from inquiries to admits to enrolled students in the most cost efficient and timely manner"[2]. Although phone-a-thon efforts typically originate out of the institution's admissions office, there are multiple audiences - including alumni, current students and faculty members - who may be tapped to participate in the calling of prospective students. Regardless of the callers or the use of multiple phone-a-thon efforts by an admissions office, the practice of phone-a-thons is not a new one. Much of the literature dates back to 1980s, with the practice emerging in the 1970s[3, 4]. Sedwick et al[5] cite a Carnegie study that confirmed the use of telephone recruitment activities throughout the United States by the mid-1980s, with 36% of all institutions reporting that they had engaged in such activities.

Although Hossler[4] notes that cultivation by faculty is an important factor in the final decision-making process of prospective students, specific citations and evaluations on the use and effectiveness of faculty phone-a-thons are extremely limited. As also cited by Hossler[4], the work Litten and Hall demonstrates that faculty members are a valued representative of the university. Prospective students and their parents see them as a credible source of information. Faculty members can provide a comfortable safety net for those prospective families who may have become disillusioned during the recruitment process[6]. The familiarity that faculty members possess about the college's programs, its graduates, and a discipline's opportunities can be of great value to a prospective student and their parents. Because a phone-a-thon fosters information sharing through person-to-person communication, faculty members can enjoy a unique moment to speak with prospective students and share those valuable insights at a critical point in the decision-making process for these young people[3].

The ways in which students prefer to communicate is becoming of great interest in the digital age. The new generation of college-bound students can be viewed as media omnivores, who waste very little time in searching for college information that is not easily and immediately retrievable[7]. Moreover, students prefer to receive immediate responses to information inquiries in a personalized format, including phone calls. As access to and reliance on the Internet for college information searching continues, its use may be shaping decade's old understandings about the use of the telephone for college recruitment purposes.

The current use of phone-a-thons as a recruitment strategy is just one aspect of an overall campus admissions plan, yet it remains a strategy that receives minor attention within the published literature. The specific strategy of personalized telephone communication by faculty members with prospective students with similar disciplinary interest garners even less attention. Thus, this paper examines the effects of enrollment in science, engineering, and mathematics at a public university in the Southwest. It makes use of enrollment and prospect data in association with three years of faculty led phone-a-thons from 2006 to 2008.

The Phone-a-Thons

The College of Engineering, Forestry, and Natural Sciences at Northern Arizona University consists of ten academic units spanning the STEM disciplines. During the fall of 2005, the official 21-day undergraduate enrollment was a healthy 2454 students including 708 true freshmen. It was broadly recognized, however, that the College, as well as the University had underutilized capacity in 2005. As such, the College became an active participant in various recruitment activities organized by the University's admissions office or initiated by its own self. One of these activities was the faculty phone-a-thon.

For each of four years, the faculty of the College participated in a two-evening phone-a-thon event held in on consecutive days, a Tuesday and Wednesday, in late November or early December. Lists of prospect students per discipline were prepared ahead of time. These lists consisted of students who had applied to the University, were qualified for admission, but had not yet made the choice to enroll. Each department was asked to supply one or more faculty volunteers per each of the two nights to staff a phone for an hour or more. The faculty came and went to each evening as their schedules permitted; beginning at 5:00 pm and ending at around 8:00 pm. The volunteers quickly learned how to use the phone and computer system and set about to calling prospects. If the volunteer was unable to make contact with the student, he or she would leave a voice mail message, speak to a parent, and/or send a follow-up email. The faculty's phone call mission was to reach out these prospective students in a nurturing manner in order to exemplify our student-focused environment and to answer questions. The ultimate goal was to increase yields; turning more prospects into enrolled freshman for the following fall semester.

Today, the College reports 4028 undergraduate majors as of the Fall 2009 official 21-day count with 1443 freshmen. This enrollment is an increase of 64% from 2005 and coincides with a multi-year growth in enrollment campus-wide that increased over the same time frame by 38%. These data on undergraduate enrollment for the College and the University are captured in Table 1.

Table 1. Official 21-Day Fall Head Count for College and University from 2005 to 2009

21-Day Fall Census	College Freshman	College Undergraduates	University Undergraduates
2005	708	2454	13472
2006	806	2655	14526
2007	1020	2989	15569
2008	1317	3530	16787
2009	1443	4028	18581

Phone-a-Thon Results

Although the College's enrollment had grown impressively over the four years of the late fall phone-a-thon effort, we were unsure of the real effect of this activity on enrollment. Suspicions were growing that this once a year, two-night activity was not impacting yields, and departments were beginning to resist yet another year of phone calling. As such, we took on the task of trying to evaluate the phone-a-thon's impact by looking for the call data, and comparing that information to student enrollment data. We were successful in retrieving this information from admissions for three (in 2006, 2007 and 2008) of the four years. Each attempt to contact a prospective student was recorded, as well as data on whether or not that attempt resulted in: a phone conversation with the prospect, a phone conversation with a parent, or a message left on a message machine or voice mail. Faculty also sent follow-up emails on those calls unanswered. Enrollment data was also collected for each attempted contact; permitting us to match student by student enrollment records to the phone-a-thon contacts.

Table 2 is a summary of the phone-a-thon results for three years. Over the two-night event for each of the three years, 29 to 34 faculty members volunteered. In total, they attempted to contact per each year: 570, 812, and 647 prospective students. They averaged 20 to 24 attempted contacts per faculty member, as shown in column (3) of Table 2. However, the faculty volunteers were highly variable their phone calling behavior with a few faculty members making upwards of 40 or more calls, and a few others making as few as 4 attempts. As shown in column (5), approximately 49% of those attempted contacts resulted in an actual phone conversation between a prospective student and a faculty member. The number of phone conversations per year totaled, respectively: 317, 361, and 306.

Table 2. Faculty Phone-a-Thon Yields for Two-Night Annual Events per Year

Year	Faculty	Total Contact Attempts/Faculty		Successful Phone Contact/Faculty		Enrollment Yield for Phone Contacts		Enrollment Yield for Non-Phone Contacts	
		Average	Stnd Dev	Average	Stnd Dev	Average	Stnd Dev	Average	Stnd Dev
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2006	29	20.25	14.51	11.07	9.61	37.23%	25.42%	31.87%	16.95%
2007	34	23.88	12.75	10.62	6.23	26.92%	18.46%	18.07%	16.55%
2008	29	23.11	10.83	10.93	5.37	22.68%	12.72%	27.25%	23.92%

Columns (7) and (9) are of particular interest to this study as they provide an indication of the effectiveness of faculty phone-a-thons on enrollment yields. Column (7) reports the average enrollment yield per faculty for those prospects who actually spoke to the faculty member. This averaged value ranged from 37% in 2006 to 23% in 2008, although the data is highly variable with instances of 100% and 0% each year. The number of students enrolled each year from this population of prospects who spoke by phone with a faculty member from their intended major totaled, respectively: 103, 85, and 68. Column (9) reports the average enrollment yield for the attempted contacts, which does not include the faculty-student conversation group, ranging from a low of 18% to a high of 27% with generally less variability than the conversation group of column (7). The number of students enrolled each year from this population of attempted contact prospects totaled, respectively: 82, 77, and 86.

The averaged yield data of Table 2 indicates that there is little difference in enrollment behavior of prospective students between whether they actually spoke with a faculty member from their possible major or if they merely received a message from the faculty member via email, voice messaging or a parent contact. Over the full data set of three years, the average yield for the prospects who spoke with a faculty member was 28.5% with a standard deviation of 20.3%. Similarly, the average yield for the prospects for non-phone contact was 29.4%. with a standard deviation of 44.2%. The University-wide data for the same years reports enrollment yields for prospects as 17.8%. The College-wide data for the same years reports enrollment yields for those prospects not contacted through the phone-a-thon as 17.3%.

Conclusions

University admission offices use a variety of recruitment techniques to attract prospective students to its campus. The phone-a-thon is one technique employed during the season when students are narrowing down their options and finalizing their decisions. A thorough literature review provides little concrete information about the effectiveness of phone-a-thons of any type on enrollment yields, including faculty-led ones. This study is unique in that it is one of the very few that presents numerical data to support conclusions about the effectiveness of faculty-led phone-a-thons. Over the three years of captured data, spanning from 2006 to 2008, we conclude that faculty phone-a-thons did not measurably increase enrollment yields in our College that serves engineering, science, forestry, and mathematics majors. However, the College did realize other, albeit anecdotal, benefits from its participation in the once a year phone-a-thon.

Faculty and departments became more informed about the overall student recruitment and admissions process. The activity helped to encourage cross-department camaraderie; bringing together faculty from different departments housed in different buildings focused on a common goal. And, finally, many of the involved faculty reported enjoying their phone-a-thon time citing the fun and interesting conversations they had once they connected with a prospective student by phone.

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Work in Progress: Engineering Student Services Center Model

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Background

Many engineering colleges have recently established student service centers to monitor and formally address in-class and out-of-class issues in student life. The fact that these centers are situated within engineering colleges, run by faculty/staff familiar with engineering education and committed to expanding the ranks of future engineers, and a convenient one-stop-shop for underclassmen in all programs, leads to responsive and effective interventions that, if needed, can connect students with additional help offered by institution-level offices. An internet search for organizations associated with the phrase 'engineering student services' reveals a variety of innovative, college-based services at institutions such as Olin College, University of Wisconsin—Madison, University of New Mexico, Kansas State University, Drexel University, Texas A&M, University of California—San Diego, University of California—Berkeley, University of Wyoming, Oregon State University, University of Washington, and Stanford University. Table 1 itemizes common and less common functions of these centers.

TABLE 1. Functions of Existing Engineering Student Services Centers

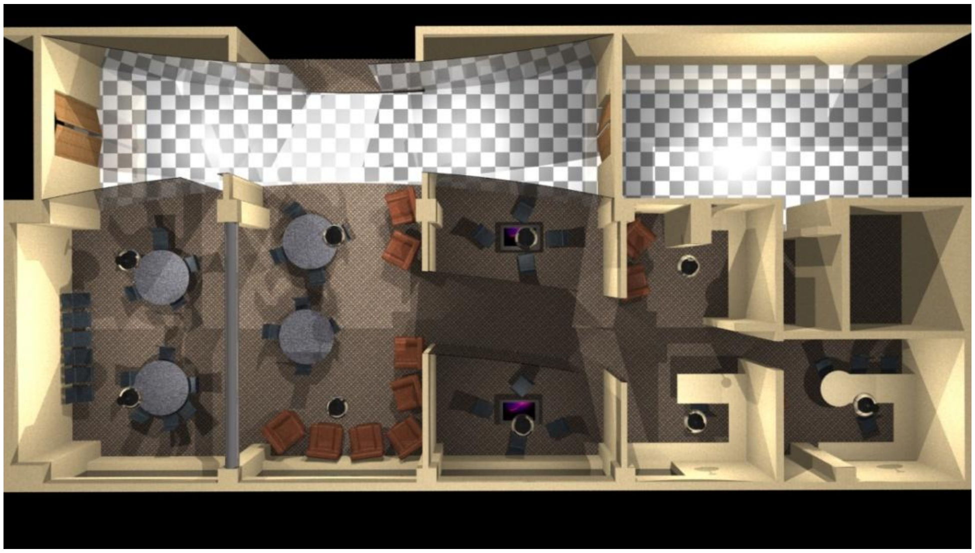
Common Functions	Less Common Functions
Recruiting	High School Outreach
Advising	Career Planning/Placement
Tutoring	Student Organizations/Leadership Development
Scholarships	International Programs
Academic Standards	Mentoring
Transfer Articulation	Honors Courses
Diversity Programs	Freshman Programs/Orientation

A common theme of all these engineering services centers seems to be elevation of learner efficacy, especially among prospective and pre-engineering students. Components of learner efficacy that need special attention are (1) realistic life vision, (2) awareness of academic standards and constraints, (3) internal versus external locus of control, (4) effective self-regulation, (5) connectedness with other students, and (6) emotional maturity. Some centers are exploring involvement of upper division students as a means for extending their impact.

Local Implementation

To better address special needs of pre-college and pre-engineering at the University, the Dean of Engineering at the University of Idaho recently challenged faculty, staff, and students to create a college-wide student services center that would become part of the Dean's office complex. The Dean further emphasized that this space should explicitly communicate (by way of people, place, and process) the message 'we were expecting you'. Faculty, students, and administrators engaged in several focus-group sessions to identify features and procedures. They also studied principles for effective learning spaces outlined by Oblinger [1] as well as best practices advocated by ACADA [2]. The design solution that has emerged through this dialogue is a visually exciting and transparent space capable of supporting a broad range of activities such as recruiting, advising, mentoring, and leadership training. The student-generated model shown in Figure 1 also includes technology enhanced spaces for team meetings and collaboration.

FIGURE 1. Proposed Design of UI Engineering Student Service Center



This project has underscored the realization that successful operation requires a coordinated effort of all engineering departments in the College. Furthermore, the delivery of center services is envisioned as a partnership between well-prepared, upper-division students from all departments and student-centered professional staff. In this way, service learning opportunities for upper-division students coexist with institutional recruiting, academic career planning, counseling, and tutoring functions for lower-division students. This presentation will overview milestones in realizing the student services center at the University of Idaho and will describe a number of student design projects that have helped different stakeholders visualize different aspects of operation. Metrics for measuring center success will also be reviewed and critiqued.

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Why Do They Come, Why Do They Not Return

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Abstract

Declining interest in engineering in high school students exacerbated by traditionally high student dropout rates in engineering have led to steep enrollment decreases in many engineering programs. While there is substantial research evidence to the contrary, many engineering faculty members continue to view the attrition positively, believing that most students who leave engineering do so either because of poor academic preparation, a lack of commitment to engineering rigor, or both. While considerable research suggests that academically successful students are more likely to leave engineering than do students who lack the necessary academic preparation[1], such research often tends to be discarded or characterized as irrelevant to a particular campus demographic. In this preliminary research, we obtain university specific data through three simple post card surveys. One survey queries students who elected not to continue their engineering course of study and a second survey queried first year students as to their rationale for final university selection. Survey results are analyzed and compared to the literature research as well as to campus baseline data. In addition, survey results for discontinuance are analyzed and compared to overall student performance and academic preparation prior to discontinuance.

Background Information

Calls for greater accountability are becoming more strident than ever and, like many universities, this call often manifests itself most strongly in the area of retention. Also like many universities, our university has explored a variety of instruments and programmatic interventions to better understand different facets of retention and improve student matriculation rates. While progress has been made, there has been no clear systematic analysis of student retention data or an attempt to correlate that data to the literature on student retention. As a consequence, student retention and persistence issues are too often driven by competing perspectives which have resulted in a variety of disconnected programmatic intervention strategies. In this paper, we provide a basis for better understanding some of the complexities of student retention by coupling local, albeit often disconnected, data to the retention literature, provide a rationale for faculty/administrative perceptions that can lead to these disconnects, and conclude with a recommendation for a more cohesive approach for systemic intervention and improvement.

Before discussing the literature and local retention efforts, it is helpful to understand a little of the history, student demographics, and local environment that governs the South Dakota School of Mines and Technology (SDSMT). SDSMT is one of six public universities in the state and is governed by a statewide regental system. While it is relatively small university (slightly over 2,100 students), all students major in engineering or science curriculum, are highly motivated, and do well on standardized tests and national competitions. Roughly 85% of the undergraduates are from South Dakota or within a 150 mile radius of the university. Two thirds of the undergraduates are white males. South Dakota has 9 reservations and slightly over 12% of the South Dakota population is Native American. Recent initiatives have been aimed at improving recruitment and matriculation rates for Native Americans and we have seen a rise from 1% to slightly over 2% Native American students over the past decade.

Retention Literature and Local Data

NSF supported statistics[2] show that undergraduate engineering enrollment declined through most of the 1980s and 1990s, rose from 2000 through 2003, and declined slightly in recent years. Undergraduate engineering enrollment declined from 420,900 students in 1985 to about 361,400 students by 1999 before rebounding to about 422,000 in 2003. By 2005, it declined to 409,300. This declining interest in engineering among high school students in recent years has led to rather sharp enrollment decreases in many engineering programs[3]. The declines in undergraduate engineering enrollment in recent years were evident for both men and women and for most racial/ethnic groups. This enrollment decline may be further exacerbated by demographic shifts that are occurring in rural areas resulting in fewer students in the high school and feeder school populations. If one couples these enrollment declines with the traditionally high student dropout rates in engineering curricula, it becomes increasingly difficult to ignore the mounting pressures for more targeted recruitment efforts and improved retention efforts. Despite considerable research to the contrary (see for example [1, 3-5]), many engineering faculty members continue to believe that the drop outs are mainly students who lack the necessary analytical skills required of the engineering discipline. In their classic study, Seymour and Hewitt[1] showed that the grade distributions of students who leave engineering are essentially the same as the grade distribution of those who stay in. That is, while a number of students drop out due to poor academic preparation or other difficulties, it is equally likely that a good student will drop out because of dissatisfaction with instruction or career mentoring. Local data reflects some of the same observations made by Seymour and Hewitt and is shown in Figures 1 and 2. Figure 1 plots the cumulative gpa for 204 freshman, sophomores and juniors who did not return to campus following Spring 2009. While one might argue that some students should leave and some students only intended to complete the first two years at our university, Figure 1 clearly shows that the campus is losing academically successful students for one reason or another. Further, the number students are large enough that it warrants further exploration to determine why academically successful students choose to leave.

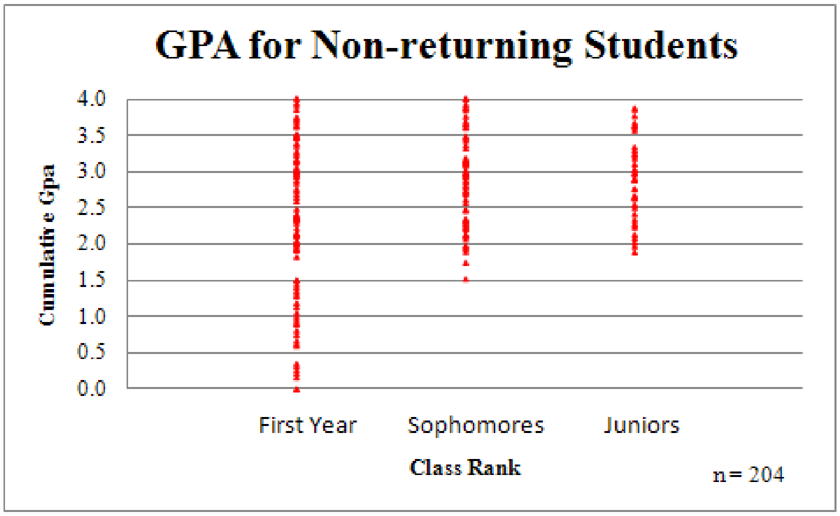

Figure 1. GPA of Students Who Did Not Return (Spring 09-Fall 09)

Figure 2 below shows similar results from a slightly different perspective and plots gpa against composite ACT scores. While the first observation that may be made is the lack of correlation between gpa and ACT composite, this not uncommon and may be explained in part with developmental theory, which is outside the focus of this paper. Here we are more concerned with academic performance for non-returning students. In Figure 2, quadrant boundaries are somewhat arbitrary but are based on gpa and act admissions scores utilized by the campus for defining at risk. We should also note that more realistic measures of student motivation and learning and studies needed for success are not included here. Such data, while useful, is not currently available for the campus. Consequently, implications from Figure 2 should be considered within the current context of defined measures for at risk.

Given the above disclaimers, Figure 2 does provide some compelling evidence indicating the need for further refinement and analysis of at risk and student retention. More specifically, quadrant I would support faculty concerns that students lack the necessary preparatory skills needed for success in engineering and science. Quadrant IV would suggest that while some students have the necessary background to be successful, they may not be motivated enough for the rigors of an engineering or science curriculum. Of primary interest to us however is quadrant III which shows academically successful students who choose to leave the university. By a considerable amount, many students who choose not to return do so for non-academic reasons.

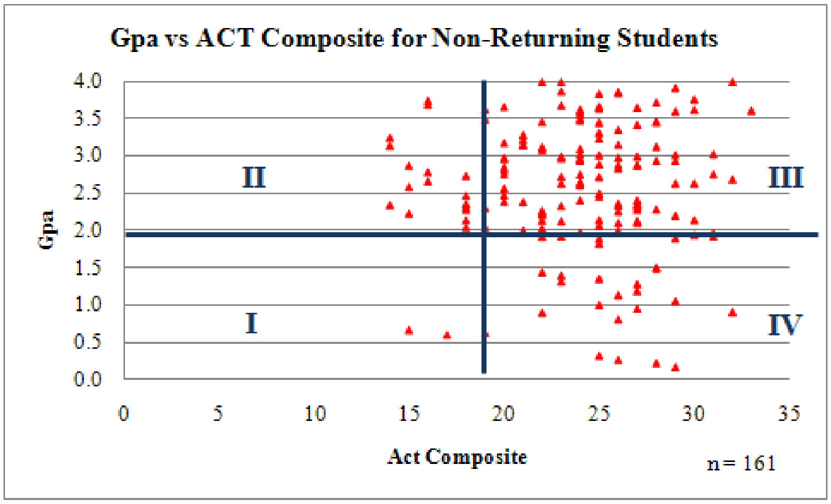

Figure 2. GPA versus ACT Composite for Non-Returning Students

Faculty concerns about students who remain in engineering through graduation are also commonly heard and are often expressed in the form that "Students can memorize and plug numbers into a formula but they do not know how to think." Although, one can readily point to faculty members (and whole programs) who manage to get many of these same students to perform at remarkably high levels, the fundamental problem remains – industry representatives, administrators, and faculty member perceptions vary regarding the rather complex arguments surrounding performance metrics and the role that both students and faculty members have in achieving those standards. Certainly, student attitudes, motivation, and studying strategies can impact academic performance. While this can be measured and positive programmatic interventions can influence student behaviors and subsequent retention, it again is not the primary interest of this paper, which is, why do academically successful students choose to leave.

Facets of Student Learning

To better understand the well intentioned, but often disjointed approaches to student retention, it is important to have some understanding of different facets of student learning, campus baseline data, how that data supports (or fails to support) the research, and how it addresses (or does not address) primary faculty concerns. In the past, our campus has focused on a number of different facets of student learning including advising and career mentoring, modes of intellectual inquiry, and student engagement and intellectual growth. Many universities also incorporate learning communities or positive intervention programs that focus on student motivation, attitudes, and studying strategies. While that has also been a thrust for this campus, the program has rested primarily with Student Affairs. Consequently, as a non-academic program, faculty members have largely remained disconnected from the program and have remained more focused on curricular or research issues.

Advising and Mentoring

Seymour and Hewitt[1] indicate that students leave engineering and science for a variety of reasons including the perceived disconnect between their career goals and program/career advising. While the importance of career mentoring is relatively well established, the actual measurement and ultimate impact on students is less clear. For example, mentoring/advising problems often cited by students include the non-availability of faculty outside of the classroom, large section sizes taught by graduate assistants, too many courses taught by non-English speaking instructors, or simply the perception of being reduced to a number; e.g., one student of many. Although these characteristics are often associated with larger research oriented universities and are not as prevalent on our campus, which has a stronger focus on undergraduate education, we are not immune to similar concerns. Indeed, retention rates at our university, while competitive, are hardly exemplary. At the same time, while retention rates have improved slightly, it is difficult to ascertain if these improvements occurred due to programmatic changes, increased faculty awareness, or a stronger commitment to career advising at the program level. In fact, may faculty members might argue that retention rates have improved slightly since the discontinuance of a mentoring program which was aimed at positive intervention.

Baseline data for advising and mentoring includes the Student Satisfaction Inventory (SSI) which is intended to measure student priorities as well as the gap between the level of importance and perceived level of attainment. Gap analysis is reported to campus departments along three primary scales: academic advising, concern for the individual, and instructional effectiveness. The SSI is completed in the sophomore year and it is this timing that is a primary concern of the faculty. Specifically, if students have completed but one or two courses in engineering how can students responsibly measure instructional effectiveness? Are students responding to general education courses or engineering? Are responses to program advising aimed at department advisors, mentors, or first year engineering and science survey courses? More importantly, there is no clear understanding of the correlation between the size of the gap and student dropout rates. Some of these faculty concerns could be alleviated if students were to complete the SSI in the senior year but logistics support is readily available only in the sophomore year. A larger concern with completion of the instrument in the senior year is that it automatically biases the results. That is, dissatisfied students would have already left and the remaining students are less likely to express areas of dissatisfaction.

Intellectual Inquiry

Other authors suggest the need to consider alternative modes of intellectual inquiry. Specifically, there is some evidence[5,6,7] to indicate that some students may leave because of a mismatch between how a curriculum is taught and their individual typology or learning preference curve. First year engineering and science students are fairly uniformly distributed across all learning styles when measured with the Kolb LSI or Herrmann Brain Dominance Inventory. Students with a strong analytical preference tend to feel comfortable with the analytical approach utilized in the traditional engineering curriculum and are more inclined to continue. Conversely, although highly valued by industry, students with a stronger creative or logistics orientation may be more likely to discontinue their engineering studies even though they may be highly successful academically.

In 2004 and 2005 First Year students were given the opportunity to complete the Kolb Learning Style index (http://ie.sdsmt.edu/firstyear/kolb.html). A plot of style types for 280 first year students is shown in Figure 3 below. While traditional engineering curriculum is aimed at the convergent style (blue shaded area in Figure 3), students are pretty universally distributed over all four quadrants. From the retention perspective, do engineering students in the accommodator, diverger, or assimilator quadrants leave due to a typological andcurricular mismatch? Unfortunately, outside of industrial engineering, there is no systematic analysis of learning typologies for matriculating students. Consequently, whether or not students leave because of this typological mismatch is unknown. Despite research to the contrary, a persistent belief remains that students must adapt to the engineering curricula required rather than the curriculum should address alternative modes of intellectual inquiry. This is likely to remain an area of debate for some time to come.

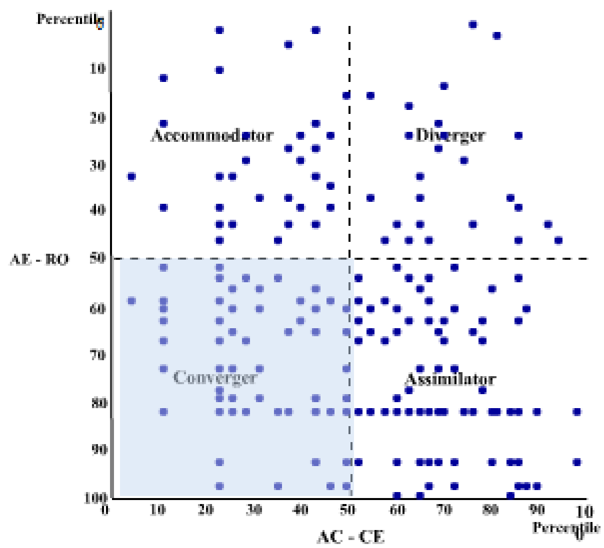

Figure 3. Kolb Style Types for First Year Students in 2005 (n=280)

Engagement and Cognition

A third facet of student learning addresses the need to engage students at a deeper level through active and collaborative learning strategies that incorporate a more constructivist approach to student learning[8]. When appropriately designed, cooperative learning elements, service learning, role plays, simulations, case work, and project based learning can lead not only to intellectual gains but to increased student satisfaction and subsequent retention. Further, both in terms of retention and in terms of cognitive development, engagement through the co-curriculum may be just as significant as engagement in the curriculum.

Several years of NSSE[9] data indicate that engineering and science students are not as engaged as they could be with the largest gap in student engagement occurring in the first and second year. The NSSE, while a useful measure of engagement provides little information as to why students may leave and offers no programmatic assessment. Consequently, there is only limited faculty interest in NSSE results. Faculty members with an interest in student engagement are already aware of the research and are more focused on programmatic assessment. Other faculty members have simply not been given a logical cohesive argument based on the NSSE data. A second concern centers on the concept of attrition bias. As students drop out leaving a smaller pool of satisfied students, engagement scores increase in the junior and senior years, but these same students were also engaged in the first and second year. The real question is why were some students engaged with the curriculum and others were not? Until there is a better understanding of how engineering and science students learn and, more precisely, why they choose to leave, curricular approaches are likely to remain disjointed. A new instrument, the E-NSSE[10], attempts to overcome some of these problems by focusing on engaged pedagogies for engineering.

An alternative measure which has greater interest to educators is critical thinking or intellectual development. The RCI is a measure of reflective judgment and describes changes in epistemic assumptions and subsequent complex thinking skills of young adults. The fundamental premise is that if students are engaged with the curriculum they are less likely to leave. Further, learning is likely to occur at a deeper level and cognitive growth will result. Baseline data for the campus was collected for First Year students in 2006 in a required Introduction to Engineering course for some 200 students. As one might expect, the average reflective judgment score for First Year students (3.5) is consistent with the research which reports an average around (3.4)[11]. While cognitive growth is the promise of higher education, gains in this area remain elusive. Intellectual gains tend to average only one-half step over a four year program of study. This limited growth supports the national NSSE data - on average, students are under engaged. The implication seems relatively clear. Students who are under engaged tend to be more disconnected and are likely to drop out of engineering and science. Figure 4 below shows the results for 70 First Year students at SDSMT for 2006 for industrial engineering seniors at SDSMT when compared to the national average for students of similar rank. While much of the literature shows little or no variation in intellectual growth between disciplines, it should be noted that the national average reported in Figure 4 is for all students in all majors. Nevertheless, the 0.84 gain from the first year to the senior year by industrial engineering majors is considered both significant and substantial.

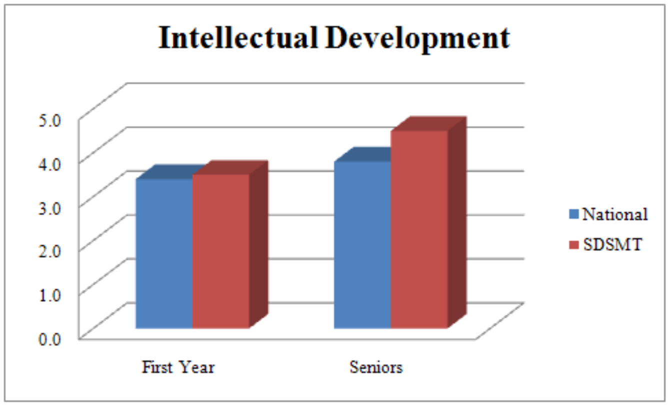

Figure 4. Comparison of RCI Scores of SDSMT Students to National Average

While this data does not directly address the question as to why students leave, it is worthwhile to note that this growth is consistent with department engagement data (SSI, NSSE) and supports the premise that engaged students are likely to be retained.

By this time, it is hopefully clear that there is a positive correlation between student learning and retention. However, the issues are complex and include a number of elements not currently measured by this campus; e.g., identity formation, psycho-social development, faculty-student interaction, student-student interaction, degree of engagement, and so on. Nevertheless, the implication is clear; the best way to address student retention is to address the multi-faceted components of student learning. In a landmark article, Felder and Brent[3] stress the importance of all three facets of student learning and cite the need to consider learning orientations to studying, learning styles, and intellectual development as a means of improving student retention while simultaneously increasing performance standards. This same general idea is put forth more formally through the holistic learner development model offered by Karlin and Kellogg[12].

Post Card Surveys

While there is campus data that is consistent with much of the research regarding student attrition, to date, that data has been somewhat disconnected and does not address the fundamental questions posed by faculty. Specifically, how many capable students leave the university and why do they leave? To address this more fundamental question, we designed two simple post card surveys modeled after the post card survey utilized at the Rose-Hulman Institute of Technology. The first post card survey was administered to 394 First Year engineering and science students at SDSMT. This survey took less than five minutes to complete and queried the students as to what it is about our university that attracted them to attend. The second post card survey had similar queries but was mailed to the 204 students who were enrolled in Spring 2009 but who did not return in Fall 2009. A third survey was mailed to 305 students who were admitted to the University but elected not to come. Unfortunately, the last response rate for this survey was too small and is not included in this report. All mailed surveys were preaddressed and stamped so that the student had only to tear off the perforated picture post card on the front, and drop the completed post card survey in a mail box. The survey format for two surveys is shown in Figures A.1 and A.2 in the appendix.

Why Am I Here Survey

Faculty teaching introductory First Year engineering and science courses administered the 5 minute "Why am I Here" survey. Of the 394 students completing the survey, 296 students visited our university prior to final university selection. A total of 214 students visited 2.1 other universities on average. Reputation and specific majors are the primary factors that influenced students to attend this university (see Figure 5).

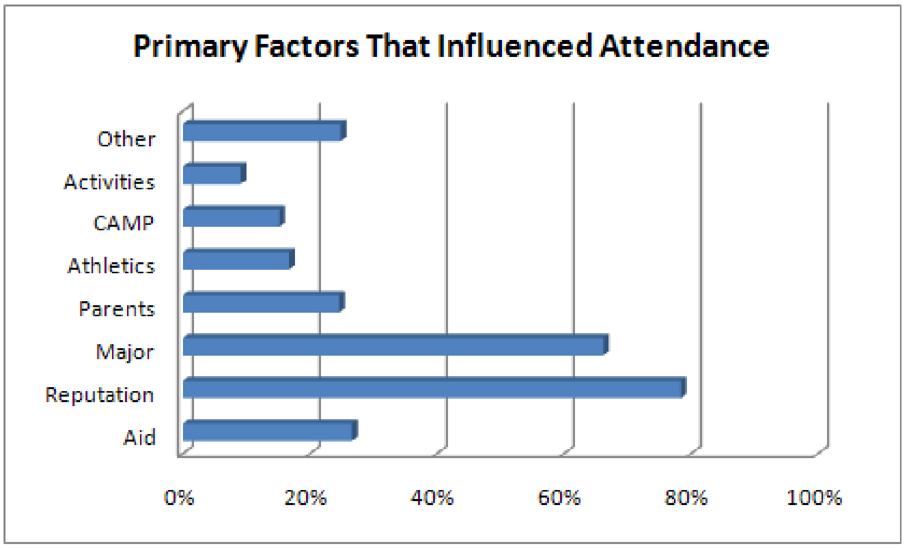

Figure 5. Factors that Influenced Current Students to Attend the South Dakota School of Mines and Technology

Question 3 of the post card survey dealt with student perceptions regarding campus facilities and support services. Results are shown below in Figure 6. Generally, most First Year students have a positive view of campus facilities and support services.

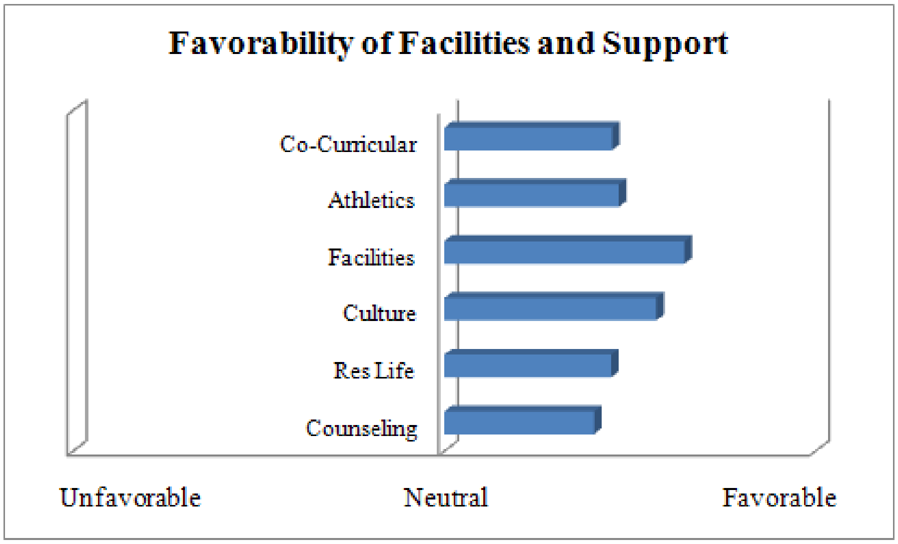

Figure 6. Student Perceptions Regarding Campus Facilities and Support

Question 4 asked students to rate various aspects of curriculum and instruction as either favorable or unfavorable. Results are shown below in Figure 7 and again, First Year students, at least initially, tend to be satisfied with their school selection and view all aspects of curriculum and instruction as favorable.

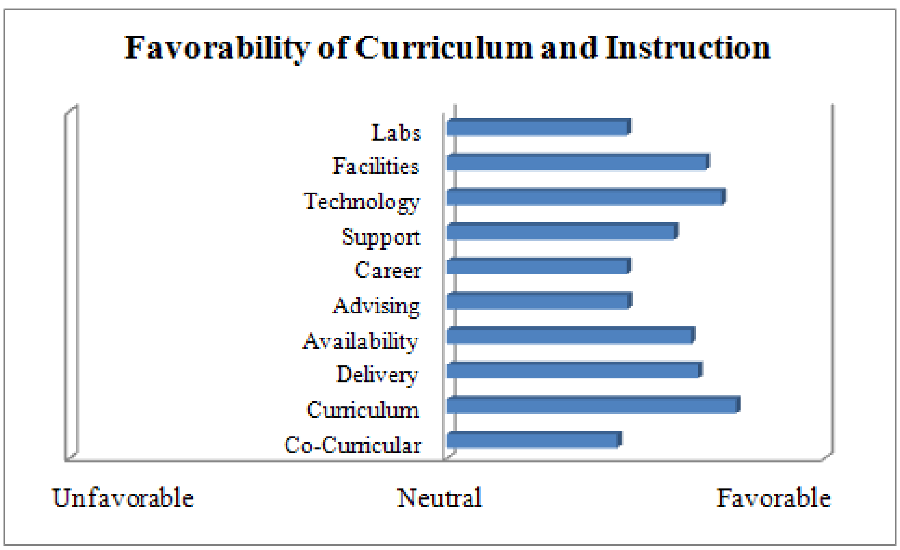

Figure 7. Student Perceptions Regarding Elements of Curriculum and Instruction

The final section gave students an opportunity to provide general comments on their experience at SDSMT. As one might expect, comments were generally positive with a few negative comments regarding university food service and facilities. Again not surprising, the largest negative for students is the limited availability of campus parking. Another negative is the temporary residence assignment to an off campus facility.

Why Did They Not Return

Not surprisingly, most First Year students are likely to feel positive about both their choice of major and their choice of schools. Consequently it should not be too surprising that student perceptions on the "Why I am Here" survey were generally positive. The one exception to this perhaps is the significantly stronger perceptions regarding the degree to which students value the majors offered on campus and the reputation of the university. The critical question of course is how these perceptions may change over time. In particular, do students who choose to leave the university have universally negative perceptions along these same factors? The second post card survey, the "Why Did I Not Return" survey, shown in Figure A.2, was mailed to 204 students who were enrolled at the university in Spring 2009 but who did not graduate and who did not return in Fall 2009. While only 28 students returned the survey (13.7% response rate), initial results from these students provide some interesting insights as to why students may discontinue enrollment at the university. Figure 8 below lists the primary reasons why students decided to discontinue enrollment at the university. Students leave for a variety of reasons including financial constraints, academic difficulties, poor advising, and so on, but, from this preliminary data, the single largest factor influencing the decision to leave is simply that the university does not offer a specific major that is of interest. Implementation strategies for next year include a coding element to determine which engineering or science major the respondent left. A secondary question is also planned capture information on missing majors of interest. Indeed, comments were generally positive and are probably best summed up by one student who wrote "I loved the school of Mines! I wish I could have stayed but I decided to switch my major to math and secondary education."

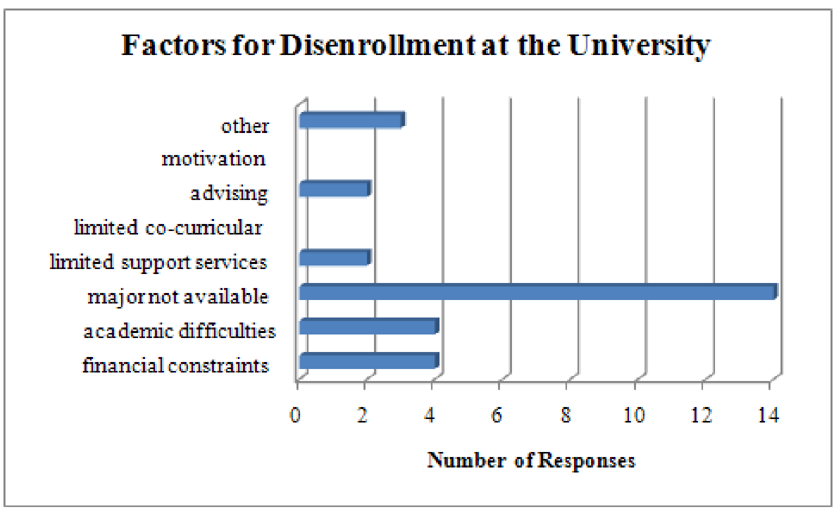

Figure 8. Factors that Influenced Students to Discontinue Enrollment

Student perceptions regarding curriculum and instruction and campus life are shown below in Figures 9 and 10.

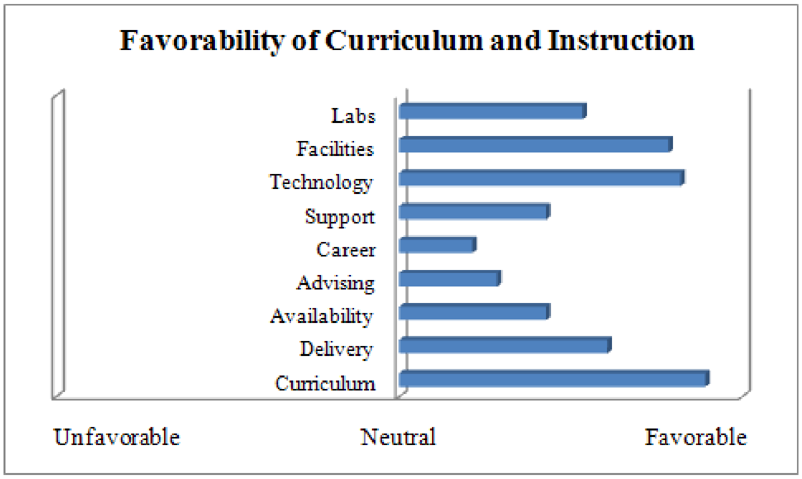

Figure 9. Non-Returning Student Perceptions Regarding Elements of Curriculum and Instruction

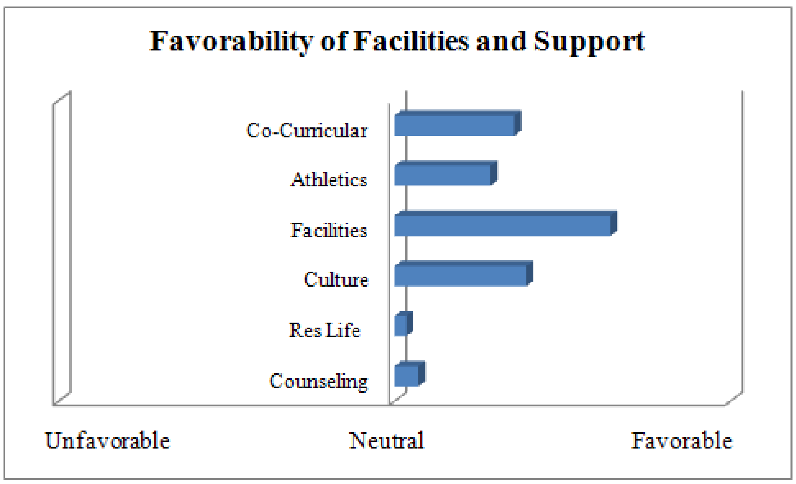

Figure 10. Non-Returning Student Perceptions Regarding Campus Facilities and Support

While students rated program advising and career mentoring lower than other curricular components they were still more favorable than unfavorable. Students were more likely to be neutral in areas such as residence life and counseling where they may not see a direct impact. It should be noted that the post card survey response rate, while consistent with other surveys, is low and additional follow up (phone calls) could be made to increase sample size as well limit return bias. Return bias results if students with a favorable view of the university are more likely to return the survey than those who do not. This return bias should be addressed if future surveys are to be conducted.

Conclusions and Recommendations

Campus baseline data clearly shows that many academically successful students leave the University for reasons other than academics. Results from the post card survey provide some preliminary information as to why students may choose to leave but are only preliminary. Nevertheless, they do provide some guidance for areas for further exploration; e.g., availability of majors, residence life, etc. Current discussions include a more formal campus effort to look at student retention through a more cohesive and systemic approach to data collection and analysis. Specific areas of recommendation include survey coding to collect information on student typology for students who choose to leave, inclusion of campus MLR and LASSI baseline data of student attitudes, studying strategies, and motivation. Perhaps the greatest contribution of this small effort is the recognized need for a university wide program for systemic data collection using multiple measures of interest to both faculty and administrators.

Acknowledgements

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Appendix
Post Card Surveys

WILL YOU HELP US?

The faculty and staff are excited to see that you have selected SDSM&T to pursue your career goals. As first or second year students, you have a unique perspective that is important to us. We would appreciate some feedback as to your reasons for selecting the School of Mines as well as feedback on how well we are meeting your original perceptions of the School of Mines.

1. Before choosing SDSMT did you?
   a. Visit SDSMT? Yes No
   b. Visit other universities? Yes No
   c. If yes to b, how many universities did you visit ____

2. Which of the following best describes your decision to enroll at SDSMT (select all that apply)?
   ____ financial aid offered
   ____ academic reputation
   ____ specific major offered
   ____ parental influence
   ____ opportunity to participate in athletics
   ____ opportunity to participate in CAMP
   ____ opportunity to participate in other co-curricular activities
   ____ other

How favorably or unfavorably to you rate each of the following?

Area Description	unfavorable	No opinion	favorable
Counseling and support services			
Residence Life			
Campus culture			
Campus facilities			
Athletic facilities			
Co-curricular activities			

4. How favorably or unfavorably do you rate each of the following?

Area Description	unfavorable	No opinion	favorable
Curriculum			
Instructional delivery			
Faculty availability			
Academic advising			
Career advising			
Class support			
Technology support			
Classroom facilities			
Laboratory facilities			

General Comments

Figure A.1. Why I am I Here Post Card Survey

WILL YOU HELP US?

We are sorry to hear that you have decided not to return to SDSM&T this term. There may be a number of reasons why this might be so and we certainly wish to respect your decision regarding what is best for you. As part of our ongoing improvement efforts, it would be helpful for us if you would be willing to take a few minutes to complete and return the short survey below.

1. Which of the following best describes your decision to discontinue enrollment at SDSMT?
   ____ financial constraints
   ____ academic difficulties
   ____ desired major not available
   ____ limited support services
   ____ limited co-curricular activities
   ____ advising
   ____ motivation
   ____ other

2. How favorably or unfavorably do you rate each of the following?

Area Description	unfavorable	No opinion	favorable
Curriculum			
Instructional delivery			
Faculty availability			
Academic advising			
Career advising			
Class support			
Technology support			
Classroom facilities			
Laboratory facilities			

3. How favorably or unfavorably to you rate each of the following?

Area Description	unfavorable	No opinion	favorable
Counseling and support services			
Residence Life			
Campus culture			
Campus facilities			
Athletic facilities			
Co-curricular activities			

General Comments

Figure A.2 Why Did I Choose Not to Return Post Card Survey

Technology to the Rescue!
Lessons learned from the forced on-line streaming of Dynamics class

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USAF AFRL/RZSE

Abstract

Fall semester 2008, an upper division undergraduate Dynamics class was streamed via Elluminate*Live*! to students on the main campus from a physically distant instructor. The course had been developed for lecture delivery through interactive broadcast television between equipped studio classrooms. This class was part of a study into the effectiveness of the broadcast environment for content delivery of undergraduate engineering courses. When the generating studio classroom was vandalized by external intruders, the lectures were ported to live interactive streaming video to personal computers. This paper will discuss both student outcomes and instructor lessons learned from that semester including comparison of results for Dynamics Concepts Inventories with other semesters, Blackboard usage during the semester, anecdotes from students, and observations from the instructor. Information from other instances of interactive streaming of coursework will be compared with the Dynamics class. Questions on appropriate application of streaming technology to undergraduate engineering curriculum delivery are raised.

The student population for the Dynamics class fall semester 2008 was NOT self-selected. Students were not informed before the first day of instruction that the course was to be broadcast and generated off campus. 30% of students answering a questionnaire at the end of the semester STRONGLY agreed with the statement: "Having class sessions on Elluminate was helpful to me". The DCI results showed moderate correlation with grades achieved in the class. However, the results for this semester were not significantly different from those for other broadcast semesters. Students accessed the site most frequently on Saturdays. The instructor found the Elluminate*Live*! sufficiently capable and comfortable to use it exclusively for a graduate class the following semester. That streaming video technology is readily available, sufficiently capable for content delivery and interaction, and some students find it helpful, raises questions about how to most productively exploit this technology for curriculum delivery.

Motivation

The motivation for porting lectures in a junior year Dynamics class to live interactive streaming technology was neither curiosity, buckling to administrative pressure, serving the needs of a grant, nor altruism for commuting and overloaded students. Desperation motivated streaming the class. Two weeks in to a new semester, just when students were becoming accustomed to the interactive broadcast environment normally used for this class, the studio classroom was vandalized and the ability to broadcast lectures compromised. The time estimate for repair of the broadcast room was about two weeks. (Actual restoration of capability took more than a month.)

Contingency plans existed for the loss of communication between sites, but not for extended periods without the ability to record lecture. So, a method to deliver content, temporarily, to students 250 miles apart in a fair and thorough manner needed to be developed between 8 am Monday, when the vandalism was discovered, and 11 am Tuesday when the class next met. Options for content delivery included using a correspondence model, having another faculty member at the main campus teach the remote section, and moving lectures to a portable video teleconference system. Having students study from the book on their own and complete homework and quizzes by correspondence was not an attractive option for this critical junior-level class. No other instructors were readily available to teach Dynamics on short notice for an unknown length of time without overloading their schedules. The portable video teleconference system, while capable of broadcasting lecture, was limited in its ability to broadcast content, like notes, and required reconfiguration for use in the classroom. A more attractive option appeared to be streaming lecture through the course Blackboard site real-time using Elluminate*Live!*. Elluminate has the capability to stream audio, video, and content simultaneously and in real-time to student computers. Students can interact with the content, the instructor, and each other by typing, mousing, or talking, depending on their system capabilities.

What was intended as a stop-gap measure to temporarily avoid a disruption in content delivery for a dynamics class continued through the entire semester because questionnaire results after several weeks of streamed delivery showed that more than half of the students in the class wanted the Elluminate sessions to continue even after broadcast capability in the studio classroom was restored.

The motivation for writing this paper is three-fold. First, after streaming the dynamics class out of necessity, I discovered I liked it and preferred it to broadcast. Study and introspection is continuing to determine why streaming was preferable to broadcast. Second, recognizing this preference, and noting that about a third of the students also share this preference, questions arise that must be answered to determine the appropriate role for streaming content in a standard Engineering curriculum. Third is a recognition that fundamental assumptions made in previous research are in error. That research effort needed to be concluded and a new hypothesis developed based on a student-centered content delivery.

Original Course Structure and Educational Research Hypothesis

The Fall 2008 section of Dynamics class was planned as an interactive broadcast class and was part of a study into the efficacy of the interactive broadcast method for generating learning outcomes in junior-level engineering courses[1]. The class is generated at the remote location to transfer students primarily from one community college pursuing a mechanical engineering degree objective through the main campus University. The distant students are on the main campus and are a mix of civil and mechanical engineering degree objective students from the distribution of students native to the main campus with a small percentage, usually less than 10%, of transfer students from main campus local community colleges. A control group of direct-contact method instruction main campus students that is not broadcast is not possible since this instructor does not teach in residence on the main campus. Similarly, the remote program does not have sufficient students to permit a second section to be taught without broadcast. So, this case exists in isolation from a control group and generalizations must be considered very carefully. Generalizations about the technological intermediary effects on transfer versus native student populations can not be made due to lack of a control group of transfer students on the main campus. And, generalizations between civil and mechanical engineering majors cannot be made due to a lack of civil engineering students in the direct-contact group.

The course was delivered in a traditional lecture style with only minor modifications granted for the technology. Modifications made in previous semesters include posting course notes and previous exams to the Blackboard site for the class, using the Dynamics Concepts Inventory (DCI) as a pre- and post-course assessment, deploying a math and calculus quiz in the beginning of the semester to intercept poorly prepared students, inclusion of more demonstrations in class, and use of some conceptual test questions that do not require calculations.

Fall 2008 was the first semester to use three full class period mid-term examinations for assessment along with a two hour comprehensive final examination. Previous semesters employed a quiz-per-week for assessment of course content assimilation along with a comprehensive final. The change from the quiz-per-week format was part of a larger strategy to change delivery styles from instructor-centered to student-centered, as part of the continuing improvement of the broadcast pedagogy. Also, the longer time period and multiple questions used in a full class period exam allowed for the addition of conceptual questions in the exam without sacrificing the ability to test student’s ability to actually calculate an answer.

Homework was done by self-selected groups of up to five students per group in an attempt to formalize the informal student-to-student interactions necessary for learning[2]. It was also hoped that more formal student-to-student interactions would encourage more student-motivated student-instructor interactions from the distant students. E-mail from students and questionnaire results from previous semesters of the broadcast section of dynamics indicated a persistent sense of isolation from some of the distant students. It was intended that formalizing the practice of developing “study buddies” among the students and by the instructor calling attention to the frustrations students have reported in communicating with the distant instruction that some of the interaction oriented frustration with the broadcast environment could be alleviated. Three graded homework group surveys were administered, one before each exam, to judge students’ participation and expectations of their groups and help with group management.

To increase student participation in the class and “ownership” of the course content[3], each student had to present an example problem to the class. The fall 2008 offering was the first time students presented example problems. The example problem serves both as a short synthesizing experience[4] for the students, and also as an excuse for e-mail interaction between the professor and each student individually.

An objective measure of course content assimilation was applied during the Fall 2008 broadcast offering of Dynamics in an attempt to develop successful methods of mitigating the perceived limitations of the broadcast environment. The Dynamics Concepts Inventory[5] was used as a pre- and post-course assessment, independent of graded problem-solution and conceptual style problems used on the exams, to judge the effectiveness of content delivery. With an objective measure of content assimilation available, the effects of changing course format, student engagement strategies, textbooks, and other tools in the lecture style of delivery could be assessed. The improvement results from DCI scores from previous semesters indicated that more conceptual discussion of course material was necessary to enable thorough understanding of the material[6]. A consistency in pre-course DCI scores while a bi-modal grade distribution developed on calculation style graded assessments indicated that some students in previous semesters required intervention for inadequate math and calculus skills.

The hypothesis of the original research regarding this dynamics class was that interactive broadcast is effective for not only generating the desired student learning outcomes of a particular class, but also for creating the learning experiences necessary to develop excellent engineers. This research was motivated by a customer expectation in hiring the graduates of the remote program. That a strong and persistent sentiment against broadcast course delivery exists is well documented[7]. When that sentiment is expressed by the person who is both in charge of hiring engineering graduates for his organization and supplying a full time instructor to the remote program, it carries significant weight in program development. Hence, the research hypothesis asserting the efficacy of the broadcast method, and employing an objective measure of content assimilation, was developed to mitigate the primary customer's negative sentiment with the content delivery method.

The remote program has developed as an alternative to "brick and mortar" institutions for obtaining engineering degree objectives in a region underserved by traditional Universities. The program is neither taught in-person by part time temporary adjuncts nor asynchronously, either on-line or by other means such as correspondence[8]. It relies on real-time live interactive broadcast for delivery of the majority of junior and senior-level courses. Lower division content is supplied by the local community college. Laboratory classes are delivered on dedicated facilities at the remote site by the full-time instructor.

Streaming Video Technology

The baseline broadcast technology for this course is a pair of similarly equipped studio classrooms over 200 miles apart both in standard University classroom buildings. Polycom instructional broadcast systems have both instructor and student focused cameras. Three screens display the content and instructor views at the front of the room and the distant students at the back of the room, as shown in figure 1. The instructor controls the camera views and content images from a control panel at the front of the room. A Blackboard website supports the course. The content storage tools for keeping the syllabus and course notes, the gradebook function, assessment and survey tools, and occasionally bulletin board and chat room features in Blackboard are used to enhance the in-class instruction.

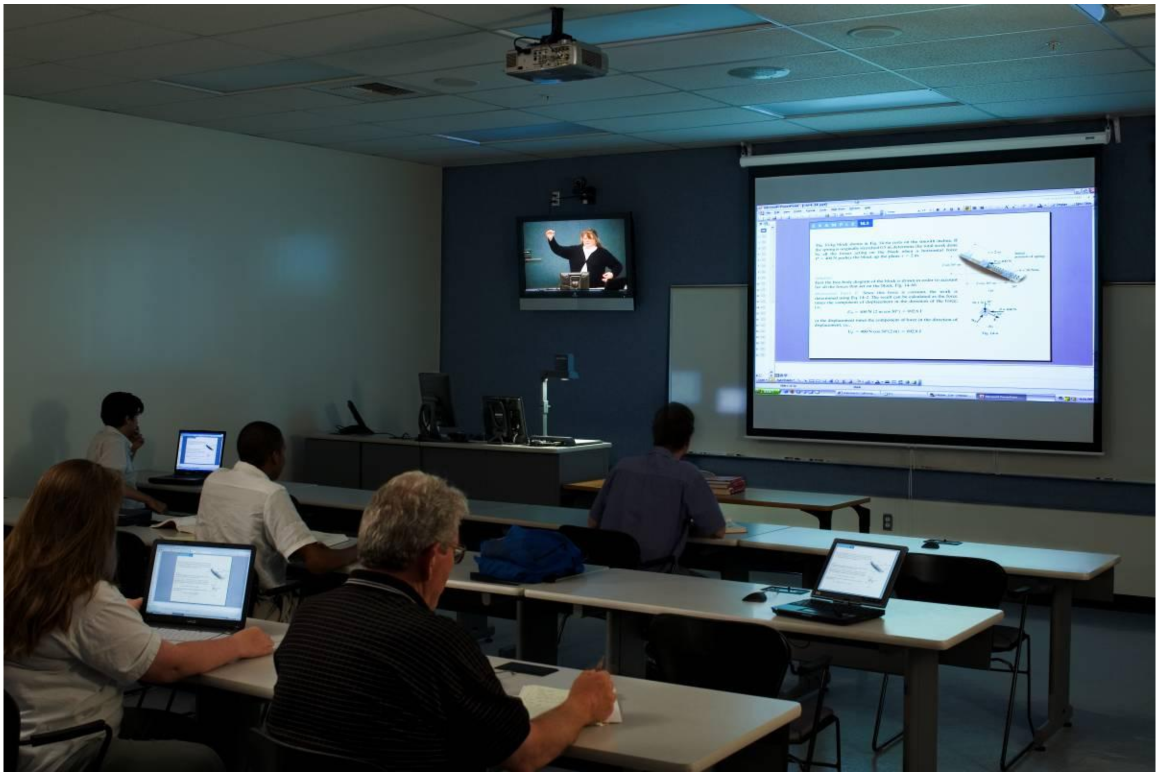


Figure 1: Studio Classroom at the remote location

Elluminate*Live*! has been embedded in Blackboard for the main campus since 2007. As a tool under the Blackboard shell for this class, it can be accessed only by students registered for the class or those specifically added by the instructor. Copyright protections are thereby maintained. And, the privacy of the classroom is maintained, unlike with open websites and chatrooms. The blackboard data base for the class and availability of its chatrooms enhance the communication potential of the system. University of South Florida and Northern Arizona University are both prominent in use of and research into the effectiveness of Elluminate*Live*! for content delivery[8], although not in Engineering.

There are several suites of Voice Over Internet Protocol (VOIP) webcasting technologies available for use by education professionals including Acrobat Connect, WebX, LearnLinc, and Live Meeting[9]. Elluminate*Live*! is resident at the main campus and supported by the digital campus organization. Elluminate advertises itself as "a virtual environment optimized for learning[10]". Some might call it a virtual classroom, or a specialized internet video conference system. It provides the functions of real-time streaming video and audio in a whiteboard frame that allows the professor to show content and write in real-time, as shown in figure 2. Students interact with both the professor and the content through typing, talking, video, or manipulating content, depending on the system capabilities of the student computer. Sessions can be recorded, or not, at the moderator's discretion. Moderator privileges can be assigned by the course instructor. Desktop applications can be shared and manipulated between session participants. (As a side note, Solidworks™ is sufficiently resource intensive that trying to manipulate Solidworks content through Elluminate inside of Blackboard crashes the computer. I have been able to manipulate Word documents, Excel files, and play solitaire on a student's machine through our system.)

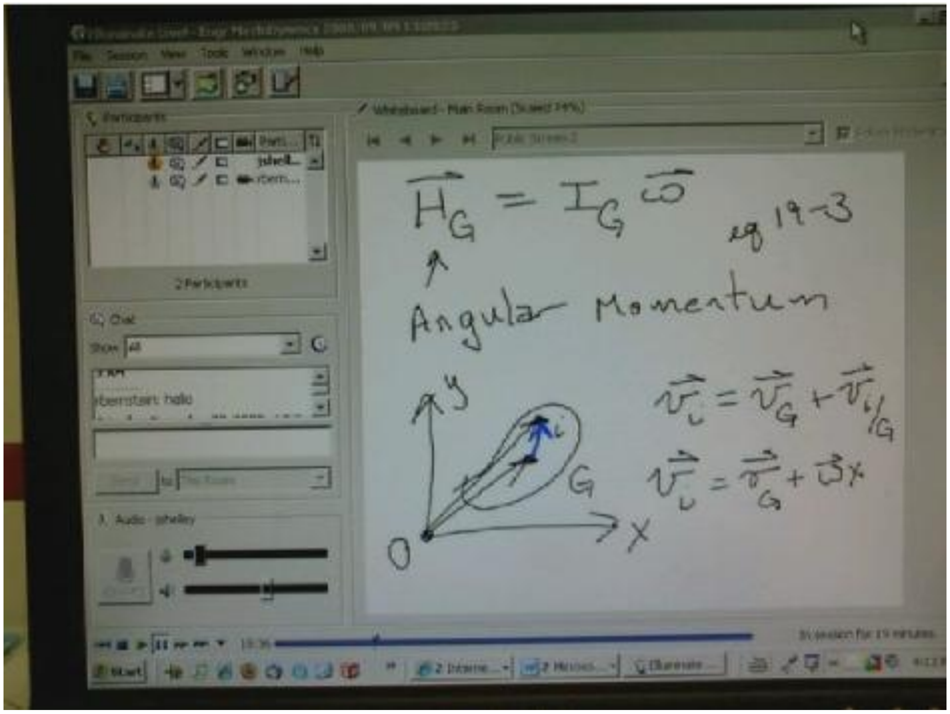


Figure 2: Picture of the Elluminate*Live*! screen recorded on 20 Nov 2008

Literature reviews appear to indicate that health care, mostly nursing, and teacher education are largest adopters of streaming technology for content delivery at this time. Many schools offer master's level classes in engineering through on-line synchronous and asynchronous delivery. While programs like University of Illinois NetMath[11] have shown success with on-line content in mathematics, no University so far discovered advertises complete undergraduate engineering degree objectives on-line. University of North Dakota offers on-line courses through a correspondence model using recorded lectures[12], but laboratory classes must be attended on-campus. While streaming video and other web-based technologies are revolutionizing content delivery and access to educational degree objectives in other fields of study, such as MBA programs, undergraduate engineering has yet to prove the efficacy of these technologies and fully embrace them.

For this Dynamics class, Elluminate was used to deliver traditional lectures and problem recitation. Students were not informed prior to the first day of instruction that the class was to be broadcast. However, the class was informed in the syllabus and during the first class session that Elluminate streaming technology *might* be employed during the semester for special exam review sessions, office hours, and homework help sessions. Streaming technologies had been investigated over the summer as a means to enhance student-teacher interactions and grant more convenient face-to-face office hours for the distance students in this synchronous distance learned class. In the Fall 2008 session, it was planned to experiment with Elluminate to enhance the broadcast course delivery in non-critical support functions, not to replace the broadcast classroom. However, regular lecture delivery through Elluminate began on the fourth class period (second week) of the 16 week semester and continued exclusively for about 4 weeks.

After the second exam, seven weeks into the semester, the original broadcast functionality was restored to the studio classroom and lectures were then streamed and broadcast live simultaneously from the broadcast classroom for the rest of the semester. Overall, 22 of the 28 course sessions (not including exams) were recorded through Elluminate to the Blackboard course website.

Data and Results

There were four students in the direct-contact section of the class and 14 in the distant section on main campus. Of the four students who could have chosen to be face-to-face with the instructor for the entire semester, one chose to participate in lecture by Elluminate throughout the semester. One student experimented with Elluminate, then determined he needed to be face-to-face with the instructor and in the presence of other students to pay attention to course material. The two others chose to be in class with the instructor for almost the entire semester due to the convenience and the timing of their other classes. The distant students had the option of participating in lecture individually in real-time, participating together in small groups, or viewing recorded sessions. Because students had options of "attending" class in groups, it was difficult to know exactly how many students were actually participating in Elluminate sessions in real time by who was logged on. At least one distant student logged into Elluminate during class sessions all semester. But, similar to the face-to-face students, initial curiosity with the virtual environment faded as the semester went on and lectures became available through broadcast. At least six distant students logged on to an introductory session to Elluminate and seemed to enjoy (two local students were logged on in the room with the instructor during the session) interacting with the whiteboard and other content through Elluminate during the session. Yet, no student took advantage of this capability during the regular class sessions.

Several sets of data exist for the streamed section of Dynamics. Blackboard records statistics for system usage. However, those data are incomplete and only minimally illustrative of the class activity. Only the data for the month of December are completely available. Blackboard records only "hits", log-ins, to particular sections of the website. It does not record how long or in what manner students used the material posted. For example, about 20% of the blackboard activity was in the Elluminate area, while most of the activity, 42%, was in the announcements section. However, the site was set to open on the announcements page so every initial log-in to the site generates a "hit" to the announcement page, regardless of what content area is "hit" next. Similarly, accomplishing a single task that requires repeated activity in one content area generates several "hits" to that area. In this case, returning exams by e-mail to students individually generated 13 "hits" in the e-mail content area to complete one task, while recording an entire class period of lecture generated only one "hit" to the Elluminate content area. Therefore, the Usage Statistics, shown in the pie chart in figure 3, for the instructor for the last two weeks of the semester show 8% of the blackboard "hits" in the Elluminate content area (Communications), 42% in the e-mail area, and 68% in the gradebook. However, personal time records indicate that the Elluminate recordings where approximately 6 hours of instructor time (not including preparation), the e-mail section required approximately 1.5 hours, and gradebook about 30 minutes. Interestingly, the usage statistics do not show student activity in the course documents section of the site, even though the class notes are posted in that area. So, while the usage statistics can illustrate which content areas of Blackboard students are "hitting", it can not illustrate how valuable students find that information or how much time they spend interacting with the material. (As a side note, the number of "hits" to the gradebook content area by students after finals week does illustrate the value students see in being able to check their grades online.)

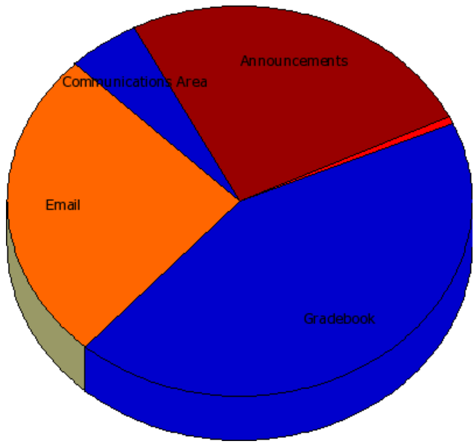


Figure 3: Instructor Blackboard Usage 1-15 Dec 2008

The Blackboard Usage Statistics for the times which students used Blackboard shows a majority of "hits", 11% of the total, where during the class times of 9:30 to 11 am, which should be expected for a class meeting through Blackboard. The second most frequent use, 10.8% of all log-ins, were in the 4 pm hour. Only two hours of the day had no log-ins, the 2 am and 4 am hours. These statistics appear to indicate that students will make use of on-line course "enhancements" outside of regular class times, even if it is just checking their grades.

That students appreciate having information available outside of class times is also illustrated by the breakout of data by week day. Taking the week of 1 Dec as an example, Blackboard shows no student log-ins during the Tuesday and Thursday class days, but 11 out of 18 students logged in over the weekend of 6 Dec. All checked grades, and two also "hit" Elluminate content. Observations of the distant classroom indicate that the distant students attend class more regularly on Tuesdays than on Thursdays. The Blackboard data reflect this trend as well with 15.4% of log-ins occurring on Tuesdays and only 7.4%, the lowest percentage, occurring on Thursdays. Just over one quarter, 25.4%, of the log-ins occurred on Saturdays. 11.7% of the Saturday log-ins appear are the instructor accessing the gradebook, email, and announcements, implying that the students access the site more frequently on the weekends than they do on Thursdays and Fridays. Overall, 42% of log-ins occurred over the weekends.

However, as figure 4 shows, log-ins to blackboard are only very weakly correlated to grades for this class, with a correlation coefficient of 0.25. While there are high scoring students who do not frequently log-in, there are no low scoring students who do log-in frequently. One snapshot of the 11 students who logged in to Blackboard on Saturday 6 Dec 08, shows that neither the highest scoring nor lowest scoring students "hit" online content that day. Since the class was not originally planned for on-line delivery and students could access almost all the required course content during the broadcast sessions, correlation between grades and blackboard usage should not be expected.

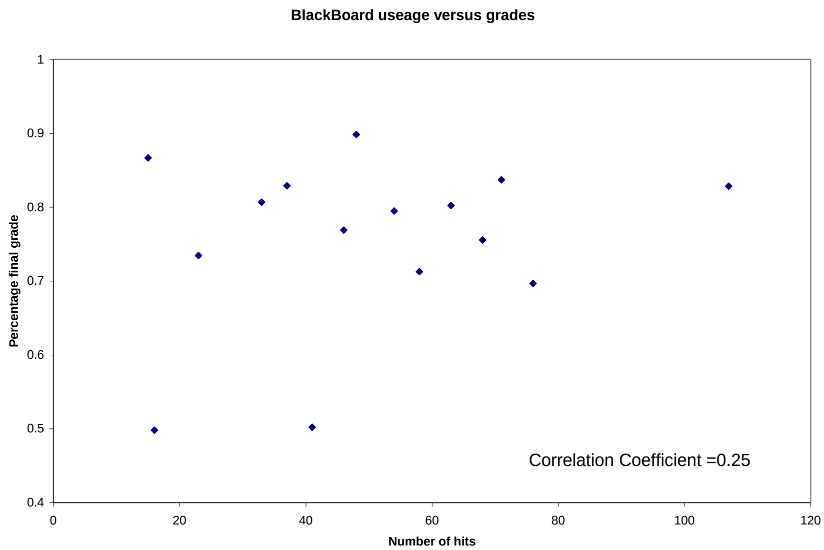
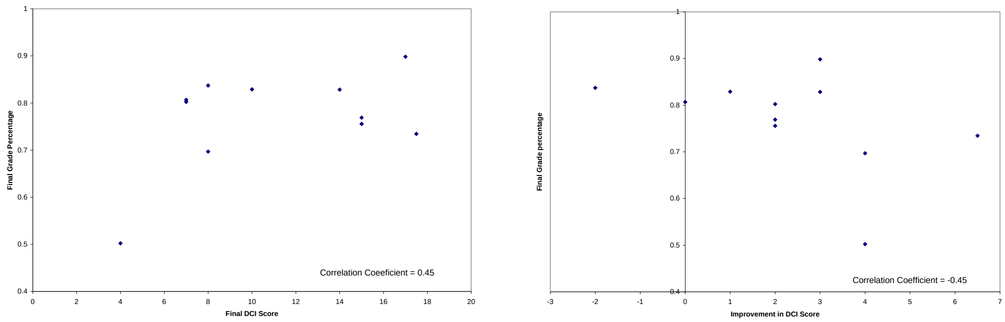


Figure 4: Student Blackboard Usage in December 2008 versus Final Course Grade

Another data set that exists for the Fall 08 offering of Dynamics is the results of the Dynamics Concepts Inventory. The results for this class were in-family with the results of previous semesters with the average score being not quite one standard deviation above the 6 correct responses expected by random guessing. 11 students took both the pre- and post-course inventories. Average score on the pre-course inventory was 9 correct out of 29 with a standard deviation of 3.6. The post course inventory average improved to 11 correct answers out of 29 possible, but the standard deviation also increased to 4.7. Two students of the 11 did not improve their score over the semester. These results are as expected from the results reported in the literature for lecture style delivery, as discussed in reference 6. While the final DCI correlates only moderately with grade achieved in the class (coefficient 0.45), *improvement* in DCI score is moderately *negatively* correlated with grades (coefficient -0.45), as shown in figure 5a and b. That DCI scores and grades correlate is within family for other strictly broadcast offerings of this course. The following semester, for example, grades and final DCI scores correlated with a coefficient of 0.48. However the grades and score improvement where uncorrelated with a coefficient of 0.15. Average scores for pre- and post course inventories where the same for those two offerings. These results indicate that the student's conceptual understanding of the material is somewhat reflected in the calculation style assessments used to generate grades. However, the calculation style of questions predominantly used on exams is not a complete measure of student's conceptual understanding. That the DCI scores and average improvement in scores are similar for several course offerings indicate that the lecture method of delivery is consistent in time and that streaming the lecture portion of the class in the Fall 08 semester did not significantly interfere with the student's ability to assimilate content.



a: Score on Post-Course DCI b: DCI score improvement

Figure 5: Dynamics Concepts Inventory Scores versus Final Course Grades

The third set of data available for the streamed offering of Dynamics is results of an instructor-generated questionnaire used to gather information on specific activities of that semester. The questionnaire and results are in the appendix. 17 questions assessed that semester's broadcast environment and pedagogy via the class Blackboard website. 14 of the questions used a five point Likert scale. There were two open ended questions: "what did you like best" and "what did you like least" and one multiple choice. To incentivize student response, extra credit points were offered for completion of the questionnaire. The survey was administered on-line through Blackboard the final week of classes for the semester. Analysis of the responses was not conducted until after semester grades were submitted.

53% of the 13 students who responded to the Fall 2008 questionnaire felt that the quality of the broadcasted Elluminate sessions interfered with their ability to learn. This response was a large degradation from previous semesters where only 16% of students felt that the broadcast quality interfered with their ability to learn. At its worst, in spring 2006, the broadcast only section responded with over 43% reporting that the quality of the broadcast was poor enough to interfere with their ability to assimilate course content. Problems with the ability of students to stay connected to Elluminate during session and the generally poor quality of the broadcast of the Elluminate whiteboard were mentioned by students as frustrations with the quality of the broadcast. (Using the stylus to write on the whiteboard in Elluminate results in a more pixilated image than when using a stylus to write in PDF software on a tablet computer. When magnified for broadcast, the results are a "stylized" writing that is a blurry low resolution image projected at the main campus classroom. When the Elluminate whiteboard is viewed on its native computer screen, the pixilation is not as noticeable. Writing with a stylus is still "stylized", but it is legible and not blurry. After Fall 2006, the standard broadcast projects a native digital image from the tablet computer in high resolution at the main campus. The difference in resolution of the projected image alone accounts for the improvement of perceived broadcast quality from 43 to 16% dissatisfaction.) PowerPoint or other native digital text methods were not employed by the instructor. Broadcasting Elluminate sessions in their native high resolution format would require a different hardware and software configuration than currently available in the studio classroom.

The root of the student dissatisfaction with broadcast quality is neither with Elluminate itself, nor with the broadcast environment when it is properly employed. The two technologies are not compatible on the system currently in use and the limitations of the technologies should be understood before choosing a method of content delivery.

45% of respondents agreed or agreed strongly with the statement that: "having class sessions on Elluminate was helpful to me." The follow-up question of asking students to explain how they used the Elluminate recorded material was not asked. However, 46% felt that using Elluminate was not worth the effort. 38% admitted that they did not take advantage of the recorded Elluminate sessions, while 23% said that used Elluminate to "attend" class over half of the time. Since the course was not intended for streamed delivery, that any students found the method useful, is encouraging of the technology. That nearly a quarter of the population did make use of the time- or location- shifting potential of streamed content indicates that there is demand, even on a standard University campus, for streamed content.

31% felt they did not have sufficient interaction with the instructor to learn the material, although all respondents agreed that e-mail interaction was acceptable. A follow-up question probing what mechanisms would be useful in creating interaction with the instructor was not asked. Similar questions asked of previous broadcast sections of Dynamics where the students were not told ahead of time that the class was broadcast indicate that about a third of the students crave the physical presence of the instructor, regardless of what other mechanisms of interaction are available. Observations of other classes and of the remote students with their main campus instructors anecdotally suggest that some students have difficulty initiating interaction with the instructor and the lack of physical presence is an additional impediment to interaction. These observations indicate that student perceptions of student-motivated interactions and methods of developing student-motivated interactions may be a useful line of inquiry in further developing either broadcast or streamed courses.

When asked what they liked best about the course, four respondents specifically mentioned having sessions on Elluminate. Two other responses mentioned the instructor's flexibility in expectation of student attendance. One response lauded the instructor's availability and speed of e-mail responses. These positive responses appear to indicate that there is demand for the flexibility inherent with recorded streamed content, as long as the instructor is available and responsive.

When the students were asked what they liked least, only one respondent directly mentioned Elluminate because it was difficult to read the projection of content. Four responses addressed the broadcast environment, projection quality, and that the instructor was not physically present. One respondent indicated that classroom discipline at the remote (main campus) site was a significant issue saying "not having an instructor present caused some students to lack the ability to shut up during lecture." (The classroom does not have open microphones.) Two responses indicated problems with instructor time management and crowding too much material into short sessions. These negative responses indicate that many of the problems experienced during this class resulted from poor classroom discipline among the students and inadequate application of technology rather than from the streaming process or broadcast technologies themselves.

When asked if they would take another course via Elluminate 38% agreed, but no one strongly agreed. 15% strongly disagreed and 23% neither agreed nor disagreed. These responses appear to indicate that while there may be some demand for streamed content in engineering, there is a segment of the student population that is heavily invested in the traditional classroom environment.

The last information available for this class is the observations of the instructor. Elluminate*Live*! is a powerful tool and only a portion of its capability was used for this class. It can be used easily to support video teleconferences with students for office hours, or casual discussions. However, the overhead in learning the system and preparing course content is significant. And, the ability of students to interact with the system is not uniform across the student population. It is limited by their individual system capabilities. To fully utilize Elluminate to create learning outcomes in students requires a different approach to the learning environment.

With that understanding, this instructor found streaming content, even under duress in a non-ideal situation, preferable to broadcast lectures. There is the potential for asynchronous access of content, and potential for the convenience of geographical insensitivity for both the instructor and student. The difficulty of maintaining discipline in the distant classroom is removed. Students participating in streamed sessions are already accepting of a technological intermediary to student-instructor interactions. Streaming also creates the illusion that each interaction is individual and personal[13]. The illusions created by and honesty of internet interactions could be able to be exploited to the student's benefit in creating understanding of subject matter and learning outcomes. It should be possible to use the anonymity of the internet and the capability of Elluminate to create a pedagogy that simulates personal tutelage, stimulates inquiry, and creates a safe environment for students to challenge their preconceived notions, or lack thereof, about motion and the unbalanced forces that cause it.

Conclusions

Contingency plans for employing technology enabled classrooms need to be broad and complete. Planning for only the loss of ability to communicate between sites and for short term loss of capability was insufficient in this case. Planning should include contingencies for complete system failure.

Where non-traditional classroom environments are to be employed, students should be informed before the class starts. Mechanisms for managing the distant classroom and enforcing classroom discipline should be developed. Sometimes intrusive methods of ensuring interactions between distance course participants are required.

While there appears to be demand for time and geographically independent content delivery even among students on the main campus of a University, there is also strong sentiment against such content delivery. That students on campus have different expectations for how learning outcomes are to be developed should be considered before porting required classes to non-traditional delivery methods.

Elluminate*Live*! is a very capable package. Only a small portion of its capabilities were employed for this class. A course developed with significant native digital format content, such as PowerPoint slides, "virtual laboratory" simulations, and application sharing could be streamed with live real-time interaction very easily. The potential for Elluminate as a mechanism for developing student learning outcomes is great, but will require careful forethought, planning, and preparation of the students.

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Appendix

Fall 2008 end-of-semester dynamics class environment questionnaire

Name	2008 DL survey
Attempts	13 (Total of 13 attempts for this assessment)
Instructions	Answer the questions honestly.

Question 1 Opinion Scale/Likert

Interactive broadcast is an acceptable way of taking a class.

Answers	Percent Answered
Strongly Agree	15.385%
Agree	38.462%
Neither Agree nor Disagree	23.077%
Disagree	23.077%
Strongly Disagree	0%
Not Applicable	0%
Unanswered	0%

Question 2 Opinion Scale/Likert

I would take another broadcast class.

Answers	Percent Answered
Strongly Agree	15.385%
Agree	30.769%
Neither Agree nor Disagree	38.462%
Disagree	7.692%
Strongly Disagree	7.692%
Not Applicable	0%
Unanswered	0%

Question 3 Opinion Scale/Likert

The quality of the broadcast did NOT interfere with my ability to learn the material covered in class.

Answers	Percent Answered
Strongly Agree	15.385%
Agree	30.769%

Neither Agree nor Disagree	0%
Disagree	46.154%
Strongly Disagree	7.692%
Not Applicable	0%
Unanswered	0%

Question 4 Opinion Scale/Likert

Having the class sessions on Elluminate was helpful to me.

Answers	Percent Answered
Strongly Agree	30.769%
Agree	15.385%
Neither Agree nor Disagree	15.385%
Disagree	15.385%
Strongly Disagree	15.385%
Not Applicable	7.692%
Unanswered	0%

Question 5 Opinion Scale/Likert

The convienice of having sessions recorded on Elluminate was NOT worth the effort.

Answers	Percent Answered
Strongly Agree	23.077%
Agree	23.077%
Neither Agree nor Disagree	15.385%
Disagree	15.385%
Strongly Disagree	23.077%
Not Applicable	0%
Unanswered	0%

Question 6 Multiple Choice

I used Elluminate to 'attend' class either out of the classroom or at a different time.

Answers	Percent Answered
Over half of the class periods of the semester.	23.077%
Occasionally during the semester.	38.462%
I never needed to during this class.	15.385%
I did not want to be out of class.	23.077%

Unanswered	0%

Question 7 Opinion Scale/Likert

The E-mail interaction with my instructor was acceptable.

Answers	Percent Answered
Strongly Agree	69.231%
Agree	30.769%
Neither Agree nor Disagree	0%
Disagree	0%
Strongly Disagree	0%
Not Applicable	0%
Unanswered	0%

Question 8 Opinion Scale/Likert

Having the students present example problems in class was helpful to me.

Answers	Percent Answered
Strongly Agree	30.769%
Agree	46.154%
Neither Agree nor Disagree	23.077%
Disagree	0%
Strongly Disagree	0%
Not Applicable	0%
Unanswered	0%

Question 9 Opinion Scale/Likert

Having to present an example problem in class helped me learn the material.

Answers	Percent Answered
Strongly Agree	38.462%
Agree	53.846%
Neither Agree nor Disagree	7.692%
Disagree	0%
Strongly Disagree	0%
Not Applicable	0%
Unanswered	0%

Question 10 Opinion Scale/Likert

Working in homework groups helped me learn the material covered in the class.

Answers	Percent Answered
Strongly Agree	0%
Agree	30.769%
Neither Agree nor Disagree	30.769%
Disagree	23.077%
Strongly Disagree	7.692%
Not Applicable	7.692%
Unanswered	0%

Question 11 Opinion Scale/Likert

Having to do homework in groups interfered with my ability to practice the material enough to do well on the tests.

Answers	Percent Answered
Strongly Agree	7.692%
Agree	23.077%
Neither Agree nor Disagree	30.769%
Disagree	30.769%
Strongly Disagree	0%
Not Applicable	7.692%
Unanswered	0%

Question 12 Opinion Scale/Likert

I felt I had sufficient interaction with the instructor to learn the material covered in class.

Answers	Percent Answered
Strongly Agree	7.692%
Agree	23.077%
Neither Agree nor Disagree	38.462%
Disagree	23.077%
Strongly Disagree	7.692%
Not Applicable	0%
Unanswered	0%

Question 13 Opinion Scale/Likert

The lack of interaction with the instructor frustrated me.

Answers	Percent Answered
Strongly Agree	0%
Agree	23.077%
Neither Agree nor Disagree	46.154%
Disagree	0%
Strongly Disagree	23.077%
Not Applicable	7.692%
Unanswered	0%

Question 14   Short Answer

Short answer: The thing I liked best about the way ME 112 was run this semester was:

Unanswered Responses
1

Given Answers
The example problems presented by the students were usually helpful, the person presenting the problem usually took a different approach to the problem than I would have, and a different approach than would have been taken during the main lecture.
testing timing in other words the time the test were set during the semester, so we had time to participate.
being able to have some flexibility in class attendance.
it was convenient the way the classes are available on time but i never used it.
I really liked the elluminate
I liked that the instructor was flexible about things.
The recording of elluminate sessions to review after class, as well as the downloadable notes of each class.
That the teacher took the time to always be available if we needed help and was fast to respond to emails.
Homework groups
I liked elluminate, presentations, i also liked the subject.
i like the example problems because I think they helped me prepare for the exams because they were exam questions that you had previously used on past exams.
I loved the instructor. She made it fun =)

Question 15   Short Answer

Short Answer: the thing I liked least about the way ME 112 was run this semester was:

Unanswered Responses
2

Given Answers
The use of class time didn't seem very good. That was largely due to problems with the distance learning set up. But I think Dr. Shelley could be a bit more efficient in the use of class time as well. I would also prefer that the class be a three (or four) day a week class, there is a lot of good material in there but it is fairly intense and that made it hard to focus on the material at hand for the last 20 minutes of the class.
Some tech issues, which delayed the start of our sessions. Other than that, class was great and fun.
that not having an instructor present caused some students to lack the ability to shut up during lecture.
The fact that it was a distance learning class. The only reason I enrolled was because it was the only dynamics class left open, the others were already closed.
elluminate was bad because could not really see anything in class.
Not being in person
nothing
The material in this class is very complicated and face to face interaction may have been best. Also trying not to cram so many chapters into the time slot available. I do not really understand chapter 19,22,20 especially the relative frame motion.
Lectures were kind of short
That I did not know it was a broadcasted class when i first signed up.
I think that this symester had a lot of problems with technology. It was hard for me to make out the board when the camera was pointed at the projector screen.

Question 16 Opinion Scale/Likert

ME 112 could be made totally on-line with recorded lectures and chat-room homework recitatio periods.

Answers	Percent Answered
Strongly Agree	7.692%
Agree	15.385%
Neither Agree nor Disagree	0%
Disagree	46.154%
Strongly Disagree	30.769%
Not Applicable	0%
Unanswered	0%

Question 17 Opinion Scale/Likert

I would like to take other courses via elluminate or with elluminate recorded class sessions.

Answers	Percent Answered
Strongly Agree	0%

Agree	38.462%
Neither Agree nor Disagree	23.077%
Disagree	23.077%
Strongly Disagree	15.385%
Not Applicable	0%
Unanswered	0%

An Evolving Model for Delivering Engineering Education to a Distant Location

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Abstract

A unique approach has evolved for providing ABET accredited undergraduate engineering education for the residents of the Greater Antelope Valley and adjacent regions in the high desert of California. Industries in the high desert have expressed a strong desire to train engineers locally. This desire stems from the unique attributes of the high desert which make attracting and retaining new graduates from other areas difficult. The model that is evolving provides only upper division instruction from the degree granting institution. Upper division instruction is provided through the use of interactive live-broadcast lectures and classes that combine students from the distant and main campus locations. A regional university center hosts the laboratories required for upper division students and is centrally located with respect to the population distribution. This approach requires the development of partnerships with the region's community colleges to provide the explicit lower division curriculum that students require to meet their degree objectives.

This paper will describe the model in its current state of evolution and report on its effectiveness for providing undergraduate engineering education to a distant location. The characteristics of the industry being serviced and the demographics of the region will be discussed as will the history that has driven this model's evolution. The necessity for the partnerships that have been formed to support this effort will be described. This paper will also report on current events that are likely to impact the model's continuing development.

The Greater Antelope Valley

A unique approach to provide ABET accredited undergraduate education for the residents of the Greater Antelope Valley and adjacent regions in the high desert of California has been evolving out of an industry driven desire to train engineers locally. This desire stems from the unique attributes of the high desert which make attracting and retaining new graduates difficult[1].

The Greater Antelope Valley is a triangular region extending from Ridgecrest, CA at the northern apex to Gorman, CA near the western apex, and the communities of Lake Los Angeles and Pearblossom, CA near the eastern apex[2]. The region defined as the Greater Antelope Valley is often referred to as Aerospace Valley. The Aerospace Valley reference is due to the fact that the Greater Antelope Valley is the home of Edwards Air Force Base which also hosts NASA Dryden Flight Research Center, the Mojave Space Port, the China Lake Naval Air Weapons Station, and Air Force Plant 42 at Palmdale Airport. These facilities have hosted the manufacture and flight test of such notable aircraft and space flight hardware as the Air Force B1 and B2 bombers, the Lockheed L-1011 airliner, the North American Aviation X-15, the Space Shuttle, the *Space Ship One/White Knight*, the world's largest liquid rocket engine (Rocketdyne F-1), and many others. As a result of the development, assembly, and test activities conducted in this region, industry is dominated by engineering disciplines at all degree levels. Regions adjacent to the Greater Antelope Valley include Victor Valley, Apple Valley, communities in the Tehachapi Mountains, and the region around Barstow, CA that includes Fort Irwin and the Marine Corps Logistics Base.

The high desert of California presents a unique environment to its residents. Joshua trees, yucca plants, and scrub cedar populate the landscape. Large dry lake beds present perfect landing areas for high performance experimental aerospace vehicles. Rainfall, in inches per year, rarely achieves double digits and the wind and sun can best be described as utility grade. It is hot and dry in the summer and cold and dry in the winter. Social amenities, such as major sports, arts, and entertainment venues, in the region's communities are minimal. The population of the Greater Antelope Valley is nearly 500,000 but it is geographically dispersed throughout the region with the largest concentration in the cities of Lancaster and Palmdale[2]. It is the minimal social amenities and the treeless habitat that make retaining and attracting people from other regions of the country difficult for employers.

The demographics of the region are changing dramatically. Located in the northernmost part of Los Angeles and east Kern Counties, the Antelope Valley has maintained lower housing costs than exist in the Los Angeles metropolitan area. Lower housing costs coupled with investor use of Section 8 housing has attracted an influx of low wage earning individuals, families, and minorities. This is evidenced by the fact that Antelope Valley High School District students qualifying for a free lunch program have increased from 28.1% to 53.7% over the last ten years with two of the 13 responding high schools reporting qualifying student populations that exceed 70%[3]. This trend is reflected in the high school district demographic data shown in Figure 1.

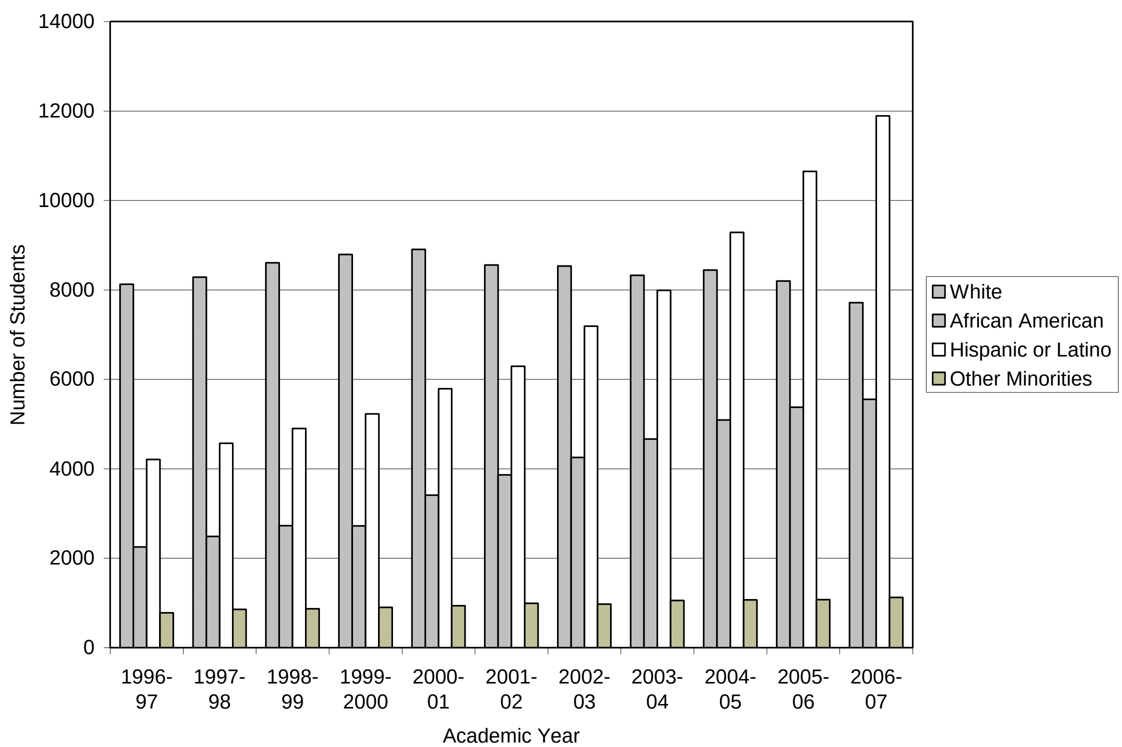

Figure 1: Antelope Valley Union High School District ethnicity trend, 1997to 2007[4]

The number of high school graduates that meet the University of California/California State University admission requirements is lower in the Greater Antelope Valley than in the state. According to the California State Department of Education only 21.5%[4] of students graduating from the Antelope Valley High School District in the 2007/2008 academic year were prepared to meet admission requirements. Both the County of Los Angeles and the State of California preparedness rates exceed the district preparedness rate by more than 10%.

For many years the Antelope Valley has been underserved, in math, science, and engineering, by higher education. Students either have had to leave the region to obtain their education or they have had to commute long distances to the nearest universities. Commute times from this region to any established campus offering engineering easily exceed one and a half hours at a minimum, can be unpredictable, and much longer depending on the weather, traffic conditions, and the student's starting location. Students from Ridgecrest at the northern end of the Greater Antelope Valley, under the best conditions, are over three hours away from any university. The alternative to long commutes has been to leave the area to obtain an education. Figure 2 summarizes data from the Greater Antelope Valley Economic Alliance which clearly shows a significant reduction in the population in the 20 to 24 year old age bracket. The trend indicated in Figure 2 is representative for communities throughout the region.

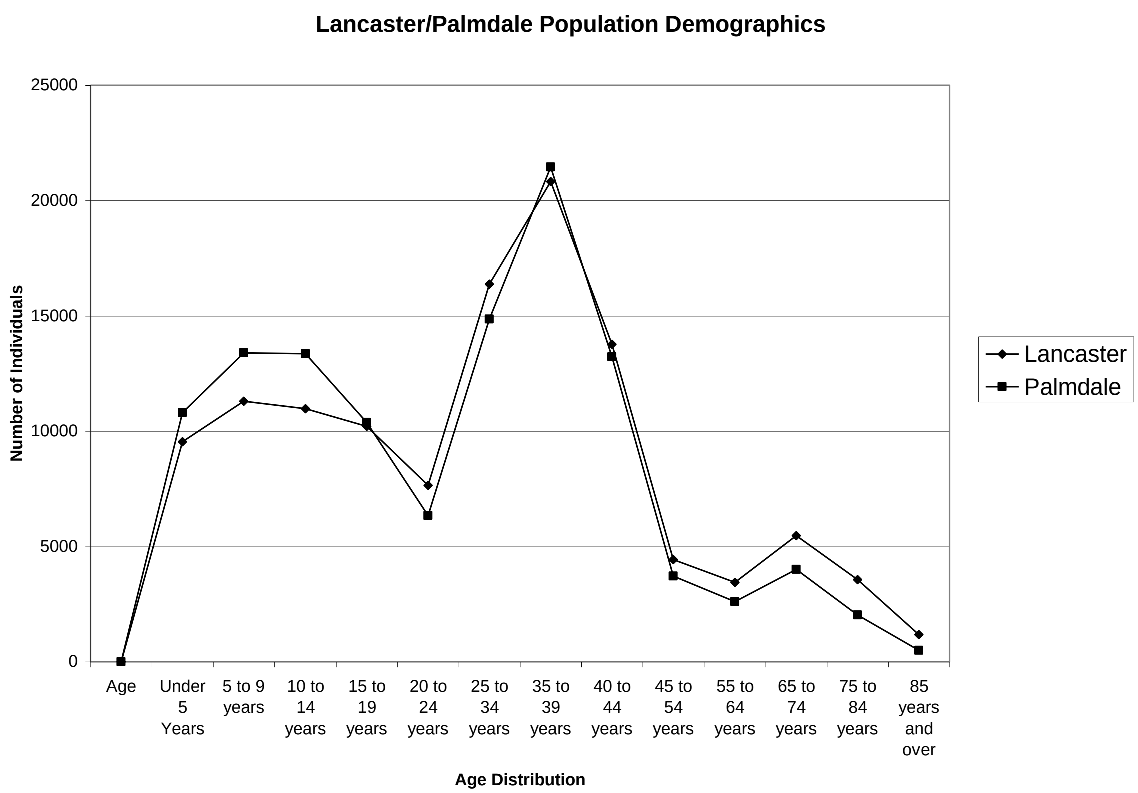

Figure 2: Population Distribution by Age for Lancaster/Palmdale Shows a Signification Reduction in the College Going Age Bracket[2]

The unique high desert environment, the paucity of social amenities, the changing demographics, and the performance of the region's schools couple together to make it difficult for the region's industry to attract and retain newly graduated engineers. Failure to retain personnel is expensive. Replacement costs reportedly run one to one and a half times the annual salary of the individual being replaced[5]. Faced with pending retirements and the difficulty in retaining personnel recruited from outside the region, industry, government organizations, local communities, and the education community have banded together to focus on math, science, engineering, and technology education, and formed (in 2002) the Math, Science, Engineering, and Technology (MSET) Consortium to increase the college going student population and to educate and graduate engineers locally. The initiative is known locally as *Homegrown*[6].

The Need for Engineering Education in the Antelope Valley

The need for engineering education in the Antelope Valley is multifaceted. The industry requirements for attracting newly graduated engineers and for retaining personnel stem from the pending retirement of the baby boom generation that heavily populates engineering, not only in the Antelope Valley but, throughout the nation[7]. There is also a need to inspire young people to enter the profession and to serve the changing population of the region by providing local higher education opportunities.

The region is also experiencing growth in solar and wind power generation as well as in other green technology industry. Photovoltaic and Rankine cycle solar power plants have been constructed or are in the permitting phase of development. The Tehachapi wind farm is being significantly expanded. Other green technology industries, such as ethanol production, are also entering the region.

Even without the new business opportunities developing within the Antelope Valley, industry data indicates that there is a need for 200 to 300 engineering graduates, at the bachelor's level, annually[4]. The industry need for engineers by discipline is shown in Figure 3. The data indicates that mechanical and electrical engineering followed by aerospace engineering, at both the baccalaureate and graduate levels, comprise the greatest need. The data used to develop Figure 3 was derived from a 25 question survey delivered to 171 organizations, within the region, that employ engineers. Organizations in the communities of Victorville, Barstow, and Tehachapi that are adjacent to the region also received the survey questionnaire. A response rate of 33% was achieved. The survey was developed using a panel of experts and a pilot study was conducted using organizations that employ engineers outside of the population surveyed but still in Southern California. Customers also expressed an equally important need for graduates that are able to communicate and present effectively. This requirement indicates the need to focus on both written and verbal presentation and communication skills[4].

The regional population demographics indicate the need for a public university in order to assure access to an education by the large underrepresented population. A local engineering program offered by a public university will help create a college going culture and it will provide a defined action plan for obtaining a college degree. Such a program will provide a destination for students who cannot afford to leave the area or who do not desire to leave for various reasons.

The poor University of California/California State University preparedness rate amongst the region's high school graduates creates a necessity for partnering with the region's community colleges. Dr. Les Uhazy, Dean of Math, Science, and Engineering at Antelope Valley College, has reported that remediation rates in mathematics typically approach or even exceed 90% of the incoming freshmen at Antelope Valley College[8]. By partnering with community colleges remediation is not an issue that the degree granting institution needs address directly. However, the required remediation rate does point out the need to partner with multiple community colleges in order to obtain a sufficient successful transfer rate into the upper division engineering program. The remediation rate also points out the need for communities to address root causes at the elementary, middle, and high school levels.

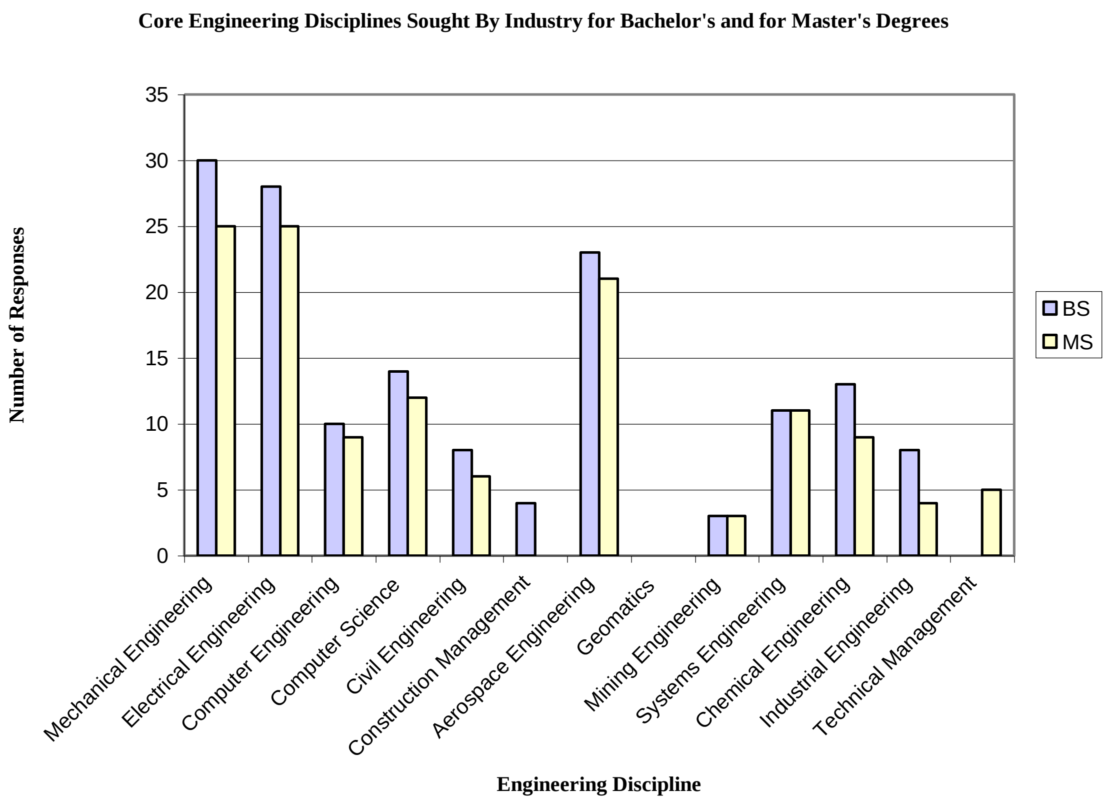

Figure 3: Industry Need by Engineering Discipline[4]

Program History and Development Background

The Antelope Valley Engineering Program derives its heritage from a graduate program initiated in 1975 to support the Test Pilot School (TPS) at Edwards AFB. In the late 1990s, the TPS eliminated the requirement for a master's degree in engineering. At approximately the same time the communities and industries in the region began to recognize the need to have a local baccalaureate program.

In 2002 the CSU Chancellor's office became involved and funded a joint engineering program involving multiple universities. The Chancellor's office funding was used to establish state-of-the art live interactive broadcast classrooms at three university locations. The Joint Engineering Program was designed to provide a local junior-year curriculum in engineering established on the Antelope Valley College campus. No upper division labs, however, were offered. Upon entering their senior year students were to choose the campus at which they would complete their degree objective.

In 2004 the City of Lancaster completed renovation of the Challenger Memorial Center, creating the Lancaster University Center. This event initiated the evolution of the existing program. Program development was initially inhibited by the lack of engineering laboratories. In 2007 the City of Lancaster completed construction of a building to house the mechanical engineering laboratory and also completed renovations within the Lancaster University Center for an electrical engineering laboratory and for faculty offices. Laboratory equipment has been supplied by the Air Force Research Laboratory and the Engineering Directorate at Edwards AFB as well as by a cooperative Department of Education Title V grant administered by Antelope Valley College. Faculty and staff have been supplied by the Air Force Research Laboratory through Intergovernmental Personnel Agreements executed with the degree granting institution.

The basic mission of the engineering program in the Antelope Valley is to provide a high-quality academic program, offered locally, that supports infrastructure development and the economic growth of the high desert region[9]. This mission has guided the evolution of the model, to its current state, for delivering engineering education at a distance. A more recent effort, that has also guided this evolution, is the research into industry needs and industry capabilities for supporting the program. This effort was initiated by defining customers and products.

Customers define the purpose of a business, or an institution, through an understanding of what it is that satisfies the customer's expectations, behaviors, situations, realities, and values. In order to obtain this understanding, who the customer is becomes the crucial first step in understanding the customer's needs (Drucker, 2001)[10].

In order to move forward with the development of this model a realistic approach suggested by Bailey and Bennett[11] which identifies employers as the customer and students as the product of higher education has been adopted. Figure 4 shows the customer/product relationship within the context of this model. Maguad[12] further defines this customer – university – product relationship.

Customer-driven organizations are effective because they are fully committed to satisfying and anticipating customer needs. The future success of colleges and universities will increasingly be determined by how they identify and satisfy various customers[13].

Products: This view helps us to focus on the end result of the students' educational process and identify the relevant skills and information that they will have upon completing the process of a course[14].

The evolving model is driven by customer (employer) needs. Identified customer needs are used to drive planning and decision making by the university/community college partnerships and by the various community consortiums that address educational needs in the elementary, middle, and high school districts (pipeline) throughout the region. This customer driven approach is consistent with Tyler's seminal work on curriculum development[16] and on Dewey's work which provided an understanding of the sources of educational objectives[17].

Employers in the region have recognized the need for a local program to educate engineers. According to an official statement from Edwards AFB,

The entire aerospace industry has a problem acquiring sufficient engineers to absorb additional work. It is critical for the long-term preservation of Edwards Air Force Base to be able to locally recruit from an educated workforce to fulfill its Department of Defense flight test missions[15].

It should be noted that Edwards AFB is the largest single employer in the region with approximately 12,000 civilian and uniformed personnel involved in the flight test mission approximately 20% of whom are engineers. China Lake Naval Air Weapons Station accounts for another 6000 government employees and uniformed personnel with approximately the same percentage of engineers.

Model Description

The model that is evolving, in the Antelope Valley, is an alternative to the traditional brick and mortar undergraduate engineering education (see Figure 4). In this model, upper division instruction only is provided by the degree granting institution and requires the development of partnerships with the region's community colleges to provide the explicit lower division curriculum that students require to meet their degree objectives.

Upper division instruction is provided through the use of interactive live-broadcast lectures and classes that combine students from the distant and main campus locations. Instruction is also bidirectional in that some instruction originates from the distant location which takes advantage of individuals from the highly skilled workforce. The Lancaster University Center hosts the laboratories required for upper division students and is centrally located with respect to the population distribution.

Lower division engineering, general education and laboratory experiences are provided by the community colleges, primarily through direct contact lecture and laboratory classes. The development of the lower division curriculum occurs in partnership with the community colleges and is in the process of being designed to be consistent between the participating community colleges such that course articulation with the degree granting institution is simplified. Curriculum and advising are the subjects of Memorandums of Understanding with each of the partner community colleges. Student advising is accomplished jointly between specified counselors at the community college and the staff and faculty at the university extension and main campus. Students are encouraged to review their progress each semester as they progress through their undergraduate (including lower division) curriculum and are provided with advising sheets detailing the program with course numbers from both institutions.

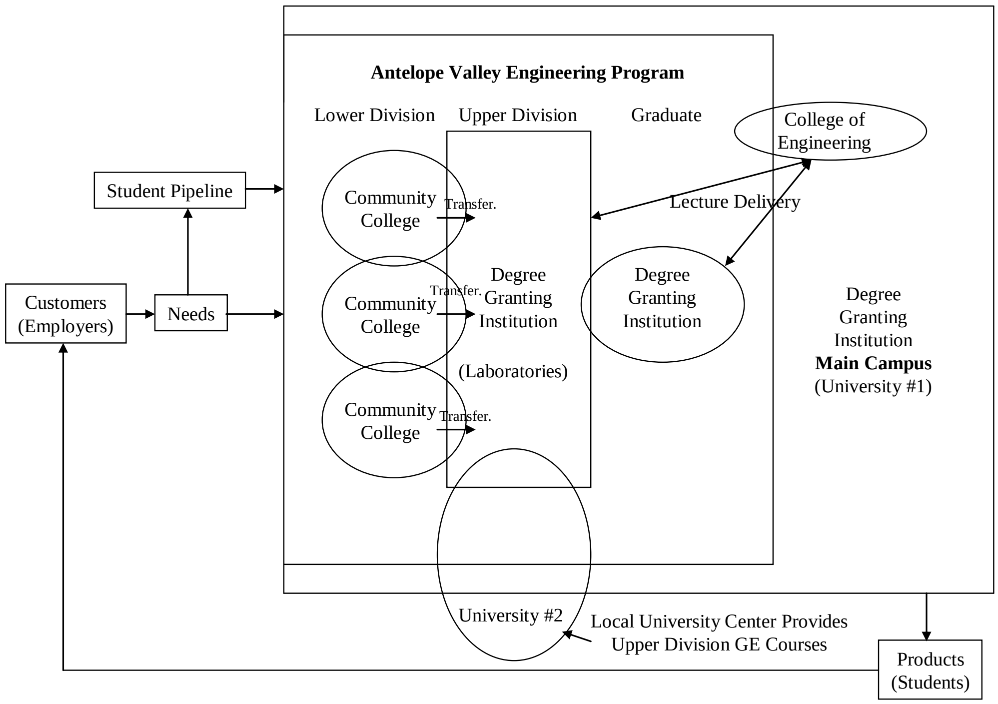

Figure 4: Antelope Valley Engineering Program Model in its Current State of Evolution

The advising sheets provide the students with the explicit course requirements by community college course number and descriptor as well as the upper division requirements once the student has successfully transferred (see Figure 5). The first four blocks of the advising sheet define the lower division requirements while the second four blocks provide the student with the information required once the transfer is accomplished. A separate advising sheet is developed for each participating community college. Multiple community college partnerships also provide students with the opportunity to obtain classes, known to articulate for their degree objective, from more than one campus. A close relationship between students in the lower division and the degree granting institution is facilitated by a community college counselor designated to support the engineering program. The counselor refers students to the upper division staff for advising appointments which allows the staff to provide encouragement, offer advice, and track student progress through their lower division curriculum. Students are encouraged to meet with the upper division staff each semester during their lower division experience. The students' close relationship with the degree granting institution during their lower division experience also helps to assure that students stay on their study plan and can transfer successfully.

California State University Fresno
Antelope Valley College
Mechanical Engineering Program
Recommended Program Sequence

Bachelor of Science Degree **http://www.csufresno.edu/luc/**

Student________________________ID#________________Advisor________________

Telephone____________________Catolog Year________________Grad Date______________

E-Mail______________________

ADVISING SHEET **MAJOR CODE: 054402**

Fall First Semester at AVC		**Spring Second Semester at AVC**	
Name (Units)	**Taken**	**Name (Units)**	**Taken**
Math 150 – Calculus I – (5)	____	Math 160 – Calculus II – (5)	____
PHYS 110 – General Physics and Lab –(5)	____	Phys 120 – General Physics and Lab(5)	____
ENGR 110 – Intro to Engineering – (1)	____	ENGR 115– Basic Engineering Drawing-(3)	____
ENGL 101 – Freshman Comp/Area A2- (3)	____	Comm 101 – Intro to Speaking/Area A1-(3)	____
CIS 161 – Intro to C Programming –(3)	____	Phil 105 – Ethics/Area C2-(3)	____
Art – Area C1-(3)*	____		
Fall Third Semester at AVC		**Spring Fourth Semester at AVC**	
Name (Units)	**Taken**	**Name (Units)**	**Taken**
Math 250 – Calculus III –(5)	____	Math 230 – Differential Equation –(4)	____
ENGR 230 – Circuit Analysis-(4)	____	ENGR 130/L – Material Science & Lab –(4)	____
ENGR 210 – Statics-(3)	____	Hist 107 or 108 – US History/Area D1-(3)	____
Chem 110 – Chemistry and Lab/Area B1-(5)	____	Econ 101 or 102 – Economics/ Area D3-(3)	____
POLSI 101 or 102 – Political Science/Area D2-(3)	____	BIOL 101 – Biology/Lab Area B2&3-(4)	____
PHYS 211 – General Physics and Lab –(5)	____		
Fall Fifth Semester		**Spring Sixth Semester**	
Name (Units)	**Taken**	**Name (Units)**	**Taken**
ME 125 – Engineering Stats in Experimentation-(3)	____	ME 116 – Fluid Mechanics-(3)	____
ME 112 – Engineering Dynamics-(3)	____	ME 118 – Fluid Mechanics Lab-(1)	____
ME 115 – Instrumentation & Measurement Lab-(1)	____	ME 136 – Thermodynamics-(3)	____
ME 134 – Fundamentals of Machine Design-(3)	____	ME 140 – Advanced Engineering Analysis-(3)	____
CE 121 – Mechanics of Materials(-3)	____	ME 2 - Computer Applications in ME –(1)	____
ME 95 – Engineering Product Development-(2)	____	PHIL 316 – Philosophy (CSUB) – (5 QTR)	____
*Completion of Writing Exam	____		
Fall Seventh Semester		**Spring Eighth Semester**	
Name (Units)	**Taken**	**Name (Units)**	**Taken**
ME 145 – Heat and Mass Transfer –(3)	____	ME 155 – Elements of Systems Design –(3)	____
ME 154 – Design of Machine Elements –(3)	____	ME 166 – Design –(3)	____
ME 156 – Advanced Thermodynamics –(3)	____	ME Tech Area B – 3 units	____
ME 159 – Mechanical Engineering Lab –(1)	____	ME 135 – Engineering Product Design-(3)	____
ME Tech Area A – 3 units	____		
PLSI 304 – Political Science (CSUB) – (5 QTR)	____		

6 units Technical Area A courses: select from ME 137,142, 144, 146, 162 or 164 3 units Technical Area B courses: ME 180, 190, 191T, ECE 121, 121L, 155

*Art – Recommended 100,101,102,110,or 147

*** Additional Requirement: Must pass the university writing exam or take IT 198W online course during the fifth semster.**

Figure 5. Example advising sheet for mechanical engineering

The curriculum represented by the advising sheets was developed using a subset of the degree granting institution's catalog requirements. The full range of electives was not made available due to the need to limit the number of classes being broadcast. The limitation resulted from the limited number of class rooms outfitted with broadcast technology. The lower division curriculum was developed in cooperation with the local community college. A combination of existing classes, modified classes, and newly developed classes resulted in a lower division curriculum offered by the community college that meets the requirements of the degree granting institution.

The result, of this approach to initial curriculum development, is similar to other programs that accept large numbers of transfers from satellite campuses such as Penn State. This approach was used due to an awareness of the Penn State model on the part of involved industry (customer) personnel in the initial curriculum development effort. The differences in the Penn State model and the environment in which this model is being evolved are, however, significant. Penn State is a single system. The California State University and the California Community Colleges are two completely distinct organizations each system having its own Chancellor and Board of Trustees. Additionally, each campus in both systems operates with a great deal of independence. The independence has allowed a great deal of flexibility and working across the two systems has, perhaps surprisingly, not posed any impediments to this evolution.

University #2, shown in Figure 4, is a manifestation of the regional consortium that has developed in the Antelope Valley. University #2 is another California State University that has established a center in Lancaster but it does not have an engineering program. Due to the local convenience that University #2 provides, a Memorandum of Understanding (MOU) was established with the engineering degree granting institution to provide upper division general education requirements to the Antelope Valley Engineering Program students. University #2 does provide, however, various student services that would not otherwise be available. The same MOU that provides for upper division general education requirements also provides for such services as student health service, library, and *Interactive Television (ITV)* technicians that also provide examination proctoring and that handle transmission and distribution of student homework assignments.

Because of the distance from the main campus (over 200 miles) engineering laboratories were established at the distant site in the spring and summer of 2007. Laboratories were developed because the laboratory experience is essential to the quality of engineering education[18]. Laboratory experiences are provided at the Lancaster University Center (LUC) by instructors on-site. Laboratory equipment has been specified by the main campus and procured in accordance with the requirements of the College of Engineering in order to provide students with the same laboratory experience that their main campus counterparts receive. The City of Lancaster has provided a building which houses a mechanical engineering laboratory capable of providing students with product development, fluid mechanics, heat transfer, and thermodynamics laboratory experiences.

The LUC hosts an electrical engineering laboratory equipped to provide students with essential laboratory experiences required to graduate. Progress is being made to expand laboratory capabilities to address Edwards AFB Flight Test needs (primarily instrumentation) as well. The mechanical engineering laboratory includes both a subsonic and a supersonic wind tunnel. Experiment equipment is modular and mobile (except for machining equipment) to allow easy laboratory reconfiguration for the various laboratory classes offered.

The foundation of the Lancaster program for this model is based on the traditional lecture style, laboratories, and project based classes. There has been no effort made at the main campus or in Lancaster to conduct asynchronous classes, or move to an on-line delivery mode, and there has been no effort to either modify curriculum or to adjust teaching style to accommodate the technology. Lectures are simply broadcast live and the technology allows interaction between the main campus class room and the distant class room. Lecturers at the distance location use the same syllabi and laboratory manuals as the main campus instructors. There is recognition, however, that additional preparation and forethought is required in the transmission of homework, quizzes, and tests, as well as material distributed during class. Contingencies for failures of the technology must also be predetermined[19] and include recording and posting lectures where distance students can access missed material using a PC.

The evolution of the model is not yet complete. There are many factors, such as customer needs, the technology employed, current economic conditions, processes, procedures, and instructional methods that require focused attention before the model can be fully matured.

Evaluation and Results

The Antelope Valley Engineering Program was initially hampered by the lack of engineering laboratories making student recruitment and degree objective completion difficult. Shortly after the dedication of the mechanical engineering laboratory in 2007, the first two Bachelor of Science degrees were awarded to students enrolled in the current effort. Since that milestone event a total of 9 BS and 12 MS degrees have been awarded. By the end of the spring semester in 2011 the number of BS degrees awarded will have increased three fold. This adds to the several hundred MS degrees awarded over the 34 year history of the engineering program in the Antelope Valley.

Seven of the nine individuals that have received their bachelor’s degree are working in the region in either federal civil service or with major aerospace corporations. One individual receiving a BSEE, did so specifically to achieve a life-long ambition, and has no intent to work. One individual just graduated as a BSME and is exploring career opportunities. One third of the graduates did so with honors. All of the individuals graduating with master’s degrees were working adults from industry or in federal service, both civil and uniformed, within the region.

Enrollment growth only really began with the opening of the laboratories and has been adversely impacted by recent events. At the beginning of the spring 2007 semester there were only 19 undergraduate and graduate students. In only two semesters enrollment for matriculating students more than doubled. The initiation of an outreach class for high school juniors and seniors, as well as Open University participants added significantly to the population of students involved in the AVEP as well. The current student population is relatively diverse with 53% Caucasian male, 26% female, 13 % Hispanic, 4% African American, and 4% Middle Eastern. Students that are employed full time in engineering positions, in cooperative education programs, stay-in-school-programs, or that have internships account for 56% of the enrolled students.

Evaluation of the success of this model is on-going and revolves around feedback from customers (employers) regarding their perceived quality of the product (students). Currently feedback is obtained in discussion with an active and engaged advisory board led by an industry partner. At this particular point in time, a Northrop Grumman program manager is the chair. The local division of Northrop Grumman, located at Air Force Plant 42 in Palmdale, is the primary benefactor of the local engineering program. Northrop Grumman has hired graduates and has several full time employees enrolled in the local program. Feedback regarding hired graduates, from the management, is positive and the feedback illuminates the importance placed on retention.

The employees that we have hired from the Fresno State LUC engineering are top notch; their level of preparedness, willingness to be in the Antelope Valley and understanding of our industry far surpass those of any group we recruit from[20].

The importance of rapid integration into the workforce is also a focus of industry concern. There is a critical need for rapid knowledge transfer due to the large segment of the workforce that is preparing to retire. The Advisory Board Chair reports that,

The LUC Engineering Program is turning out some top notch engineers. The engineers that we have hired have hit the ground running and have proved to be far more productive much sooner than those of the other schools we have recruited from[20].

Industry is also concerned about employee professional development. With respect to existing employees industry leadership has reported that,

The LUC Engineering Program is a very positive [impact] for the Antelope Valley. The program has allowed many of our employees to further their higher education close to home, and in a much less disruptive manner than we normally experience. The students/employees, working with the LUC and industry partners gain valuable insight learning close to home and industry. The program has been a great success[20]!

This evolving model appears to be effective in providing students with the fundamentals required to be successful in their chosen engineering disciplines. Distant location faculty members report that transfer students from the local community college are very well prepared to enter the upper division program. Employers indicate that they are very satisfied with the graduates that they have hired[20]. Employers also report that graduates are integrating rapidly into the work force. Anecdotal evidence suggests that communication skill development is a natural outfall of being a distant student due to the need to communicate accurately with peers and instructors from a distance.

Instructor and student satisfaction measures[21] are also important means of measuring continuous process improvement as are grade comparisons between students at the distant location and at the main campus. Such an evaluation has been under way by Shelley[22] who has reported that in Dynamics Concept Inventory results and student's grades there is no strong influence evident between the direct-contact and broadcast student populations. Shelley also reports that, even though there is no strong influence in learning outcomes, there is significant dissatisfaction identified by students due to feelings of isolation and a lack of instructor and fellow student interactions[22]. This finding is consistent with the research conducted by Salisbury et al[21].

Vision for Future Evolution

The vision for the evolution of the model is to continue to develop a geographically distributed alternative to the traditional brick and mortar and on-line engineering education program to satisfy our customer's needs.

This evolution will be accomplished by:

- Maintaining the junior-level transfer approach to program admission

- Expanding the community college partnerships to increase the transfer student population base
- Establishing program articulation with community college partners (articulation is currently accomplished course-by-course)
- Establishing joint facility use agreements to deliver courses via live televised broadcast
- Maintaining and expanding the regional laboratories to include joint facility use agreements at community colleges
- Employing continuous process improvement to advance model evolution
- Facilitating innovation and experimentation in delivering engineering education
- Taking advantage of the highly skilled and talented workforce to provide qualified part-time adjunct professors
- Establishing and maintaining data driven decision making processes
- Establishing and maintaining well documented operating procedures, based on best practices, that are consistent between partners
- Maintaining an engaged and structured industry/community advisory board to assure that customer needs are being addressed, that the effort is receiving needed regional support, and to provide feedback for evaluation

It is the considered opinion of the local staff that there are many opportunities for innovation for the institution implementing this vision in the Greater Antelope Valley. Research into changing the existing paradigm regarding engineering education at the undergraduate level, opportunities for technical research with organizations within the region, and the development of an extension offering tenure track faculty opportunities are areas of program development that can be addressed and that will facilitate the evolution of the model. It should be noted as well that this vision has been evolving as a result of a necessary effort that has developed from a grass roots regional initiative launched in 2002. This grass roots effort was led by Mr. Robert Johnstone and Mr. Bill Lawrence, both volunteers who are retirees from Edwards AFB. Their efforts resulted in the establishment of the regional Math, Science, Engineering, and Technology Consortium (MSET). It should also be noted that the evolving model and the resulting vision is consistent with opinions expressed by the National Academy of Engineering (NAE), Center for Advancement of Scholarship on Engineering Education CASEE)[23].

Current Events Effecting Model Evolution

The existing degree granting institution has determined, after considerable evaluation, to phase out involvement in the Antelope Valley Engineering Program. The economic conditions that currently exist in the nation and, particularly in California, are a significant factor that is adversely effecting the continued development of the model. The California State University system has responded to the fiscal crisis by reducing system wide enrollment by 40,000 students for the first time in its history. The CSU campuses have also implemented enrollment caps and penalties for departments exceeding their caps. Therefore, Full Time Equivalent Student enrollment is no longer an incentive for growth. No applications for admission to the spring 2010 semester have been processed system wide. These actions have had the effect of reducing AVEP enrollment by one third. Sustainability is a key issue that must be addressed through sources external to the public university system which dictates an engaged, innovative, and committed advisory board activity. In spite of the challenges, two public universities have expressed interest in offering engineering education programs at the Lancaster University Center. One of the universities is seriously evaluating the opportunity and may be at a decision point sometime during the first quarter of calendar year 2010. A positive decision is critical to the continued evolution of the model and the region is taking every available step to insure that such a decision is rendered.

Conclusions

The evolving model is effective in delivering a high quality engineering education to students. The model does not rely on asynchronous content delivery. The model does rely exclusively on community college partnerships for lower division course content delivery and the partnerships forged to date are collaborative and the relationships are strong. The customer focus is yielding good industry interaction via an engaged and committed advisory board and industry/community support for the effort is strong. The model has been developed as a result of local needs independent and ignorant of but in alignment with the opinions and activities of organizations such as NAE/CASEE. The continued success of this model has significant potential for changing paradigms regarding undergraduate engineering education.

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Using Sports Coaching Techniques to Enhance Project Based Learning Instruction

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Abstract

As instructors attempt to apply project based learning as a preferred pedagogy for many aspects of engineering education, countless questions are raised. For instance, how do instructors assess individual performance in a team based environment? How do instructors prepare students for the culminating presentation or report? How do instructors develop the students individually? After reviewing literature on both project based learning and exceptional coaching, we have found that much can be learned from John Wooden, Phil Jackson and other coaches. This paper will organize some of the best practices in sports coaching and draw parallels that will enhance student learning in project based instruction. The paper discusses the parallels between the instructor and the coach and highlights three broad categories of techniques: 1) Practice and games, 2) Teamwork and individual performance, and 3) Individual feedback for improvement. Some of these techniques have been used to successfully enhance learning in a senior design course in Industrial Engineering at Cal Poly. The insights in this article will open up a rich area of information to enhance project based learning in the future.

Introduction

Because Project Based Learning (PBL) is a new technique, much is still unknown about ideal practices. In order to shed light on the subject, the extensive literature and practical knowledge on sports coaching is explored to enhance PBL instruction. Team sports are much like PBL. Students like athletes work together for the team's success. Students like athletes must draw on individual contributions to achieve team goals. Students like athletes must practice their skills in order to be ready for the culminating game or presentation. And students like athletes must have individual feedback in order to improve. The parallels continue.

PBL instruction has only recently been a preferred means of instruction in engineering, while sports have been around for eons. There have been many great coaches through the years that have written much on how to achieve success on the court or field. This paper discusses the ways in which the literature on coaching has been used to influence teaching practices in a senior design course using PBL.

The paper first reviews literature on the subject. Next the roles of both the coach and the instructor are explored to draw parallels between coaching and PBL. This is followed by a discussion on techniques used by some of the best coaches organized into three main areas: 1) Practice and games 2) Teamwork and individual performance, and 3) Feedback for individual improvement. Incorporated in the three areas is a summary of the applications of coaching techniques in a senior design class. Finally, the results from using this methodology in a senior design class are discussed.

Review of Literature

The advantages of PBL for students learning are many[1]. Students learn to work on teams, they are able to see the culmination of a larger problem than they could have done alone, and they often achieve better design solutions.

Most engineering schools use team based projects, or team laboratory assignments to help students develop skills necessary for their professional careers. Teamwork skills have traditionally been developed by exposing students to team activities without discussion of teamwork techniques. To some extent, this lack of formal instruction does produce results, but a better approach was undertaken at the University of Dayton[2] where student teams were instructed on teambuilding and leadership. Many researchers have struggled with the difficult task of assessing teamwork and other soft skills involved in multi-disciplinary PBL teams. Plumb and Sobeck[3] put together a framework for developing assessment tools. They urge instructors to develop a rubric to track performance over time.

Teamwork in PBL is unique in that the teams are usually working on complex, ambiguous, and time consuming problems. When PBL is used students achieve many desirable outcomes. Several researchers at the University of Madrid[4] found that PBL used in the design of electronic systems increased interest in electronics, increased academic performance, and produced better design solutions. In addition, situational factors were found to influence the outcomes of PBL activities for junior engineering students[5]. These situational factors include the type of project selected, the learning of the individual student, and the ability of students to adapt to working under time pressure.

Engagement is often cited as an important component of learning in PBL. In the Civil and Chemical Engineering school at RMIT, researchers[6] examined the factors that effect engagement in a PBL environment. They examined first year engineering students and identified factors that helped students engage in a project. The first factor is that students need “interesting work.” The second is that students must understand the structure of the problem with clearly defined expectations. Thirdly, students work best when they feel connected to other students in their groups.

Although much has been written on PBL and its benefits, there is a lack of specific techniques that an instructor can use if he is inexperienced in this type of instruction. Conceptualizing PBL instruction as a coaching activity may help satisfy that need.

There are many great coaches and much written on each. In the area of basketball, every passionate coach would include John Wooden[7] as a fantastic role model. He often mentions his view that coaching is teaching and he took the responsibility seriously[8].

John Wooden’s “Pyramid of Success”[8] has informed many on not only sports skills but life skills also. The title of Swen Nater’s book on John Wooden reflects Wooden’s passion for individual development: You haven’t taught until they have learned.

Phil Jackson[9] extends activities on the court to life lessons. He focuses on success through selfless team play and spiritual practices to help focus team activities.

Jenkins[10] reviewed an interesting book, The Sports Coach as Educator: Reconceptualising Sports Coaching that attempts to conceptualize the coaching function as an education function. He reviews many theories in education and outline how these can be used in sports coaching. Drawing parallels regarding the two functions is similar to this current paper.

Edwards and Selman[11] outline the parallels of coaching to management. They discuss how much can be learned form the great coaches of the past: George Allen, Red Auerbach, Tim Galloway and John Wooden. They have also included an informative list of techniques that have proven successful on the playing field and in business. These include issues like “be clear it’s a game, and that the point is to win” and “Be committed to the players” and “Be a teacher.” Their article is good background on the subject of coaching and its transferability to other disciplines.

Given the need in PBL for specific techniques and the wealth of information in sports coaching this paper explains the use of the later in a specific course in the Industrial Engineering (IE) curriculum at Cal Poly, San Luis Obispo.

Defining Parallels

To begin conceptualizing sports coaching and PBL instruction it is helpful to examine the similarities and differences. Table 1 outlines the major components of each discipline in order to help to reader adjust to the concepts. Throughout the paper some of these components will be used interchangeably. For instance in many instances, the athlete is the same as the student. As Table 1 illustrates, although there are many similarities, there are differences too. For instance there is not as much competition in PBL instruction and the concept of opponent is not as well defined.

Table 1: Parallels between Sports and PBL

Domain	Sports	PBL
Culminating activity	Game	Presentation and report
Mentor/authority	Coach	Instructor
Participants	Athlete	Student
Duration of activities	Season (5 months)	Course (10 weeks)
Motivation	Team achievement	Team achievement
Adversary	Other team	Client
Domain	Court	Company/division
Goals	League champion	Exceptional performance
Level of competition	High	Low

The PBL Course and Projects

For more than ten years the students in a senior capstone IE course at Cal Poly, San Luis Obispo on Facility Design has work on projects for local companies. The local company is the customer and is dealt with as a client in a consulting practice. The students work in teams of four to seven students to produce an improved facilities design expressed in a report and a presentation. This capstone senior level class requires that students draw on their knowledge from many IE topics including inventory control, project management, ergonomics, quality, work design and economics. Clients are usually small manufacturing firms in the San Luis Obispo County area. Typically these firms are so small that they would never have had the opportunity to see IE topics applied in a systematic manner by knowledgeable individuals. An overwhelming number of the clients have been pleased with the results. Table 2 is a partial list of companies and projects. Some of these companies have hired IE’s after realizing the contributions IE's can make to a company's efficiency. In addition, most companies have implemented at least some of the recommendations made by these students.

Table 2: Sample Projects in Facilities Design Course

Company	Location - CA	Company Type	Project Description
C&D Aerospace	Santa Maria	Aerospace	Redesign of an assembly cell
Hardy Diagnostics	Santa Maria	Biomedical	Design layout for a new location
Left Coast T-Shirt	San Luis Obispo	Screen printing	Re-layout production floor to incorporate new machine
SLO Roasted Coffee	Los Osos	Food	Design new layout to incorporate new packaging process
UVS Thrift Store	San Luis Obispo	Non-profit	Re-layout and methods improvement

Students also learn firsthand topics that are difficult to teach in the classroom. For instance, students learn the importance of positive interactions with clients, methods of dealing with project uncertainty, real deadlines where more than a grade is at stake, and team conflict resolution in real time.

As an example, a student team made up of six seniors worked for a local Unmanned Aerial Vehicle (UAV) manufacturer to develop a plan for their new campus. Initially, the students visited the current location for a tour. This was followed by the students creating a Statement of Work as learned in their project management class. This was discussed with the client and then expanded to include descriptions of tasks, deliverables, and a work breakdown structure. The students spent the remaining seven weeks of the quarter developing a facilities solution that took into account the company's manufacturing processes, economic constraints, management needs, work flow, inventory methodology, and secrecy concerns and put together a comprehensive plan for the new location. A complete report, approximately 100 pages long, a professional presentation, and a physical model of the recommended facility was delivered to the client. The quality of the report was high and the client was pleased with the many creative benefit - cost justified ideas. In fact the client sent the following note.

"I was blown away with the quality and depth of what these students… produced. Ken will be working with Jeremiah to adopt recommendations presented in the Facility Design. Scott will be picking up on the data and trades presented in the Campus Project."

Although this course has created a successful PBL opportunity for students, this last year some coaching concepts were incorporated that have enhanced learning. Specifically the conceptualization of the teacher as coach and the employment of specific transferable techniques were used.

Role of the Teacher/Coach in PBL

The role of a coach and the teacher as a leader is very important. In this leadership role, the instructor or coach serves as a role model. This is most effective when the instructor or coach has a reciprocal respect relationship with the students or athletes. Athletes or students with a good relationship with the coach or teacher will want to achieve in order to please the coach. This type of leadership is also known as charismatic, a very effective method. Some techniques to enhance the coach/athlete or instructor/student relationship are listed below.

Communication
Students and athletes function better when they feel both included in the process and listened to. In the women's basketball program at Cal Poly, open communications are valued. Athletes hear the coach's values and goals everyday at practice and meet individually with the coach every other week. They receive feedback on the court during practice and are encouraged to approach the coach as often as necessary when issues arise. Similarly in the senior design course, the instructor communicates expectations and goals to the entire class in a lecture setting, gives feedback to the students in individual team meetings, and encourages students to attend office hours if questions arise. Every athlete and student must understand the purpose and goal of the activities. Open communication is valued not only with a student or athlete, but with every stakeholder in the activities. The instructor in the design class establishes good communications with the client company. This includes initial contact explaining the expectations for the company, a mid-quarter review of project process, and periodic emails checking on student interactions.

Love the Game
It is widely recognized that good coaches must love what they do. This is often in the context of small or nonexistence monetary compensations, but even if compensated, good coaches communicate their passion for the game. This is also true when an instructor is coordinating PBL. PBL often requires extra work and coordination when dealing with students in such an intense activity. The instructor of this engineering design course often communicates the love for the teaching profession and the joy in the success of the students. This kind of passion is contagious to students.

Ethical Behavior
Coaches must model ethical behavior on and off the court. Good coaches reward good attitudes by athletes and would never want to win if it includes any unethical behavior. This is true in PBL instruction. Teachers encourage ethical solutions and ethical dealings with the client. This includes open communications about ethics, highlighting the opportunities to behave ethically. Issues of team member's participation or lack thereof, client interactions, and professional activities are openly discussed. Through the open communications the instructor can model the expectations in the specific context of the project. As an example of an ethical situation in a project worked on this last year, the company decided they had given us proprietary information regarding processes and asked the students to shred the process instructions. The students felt that the information would help them develop a better solution and didn't want to shred the information. This was discussed openly and the ethical dilemma was clearly explored. Ultimately the students came to the conclusion to destroy the documents following the company's instructions.

Coaching Techniques

Beyond the role for the instructor, there are techniques used in the PBL projects that are derived from good coaching techniques. These techniques are divided into three loose categories. First the relationship between the practice or preparation time and the actual culminating activity, the game or the final presentation, is discussed. Secondly, the concepts around teamwork, particularly the techniques that allow students or athletes to put aside individual recognition for the good of the team, are explored. And lastly the flip side of teamwork, the development of the individual is discussed.

Practice and Games

In basketball, preparation occurs during practice and the results are seen during the game. In PBL instruction, preparation takes place during team meetings, individual task accomplishments, and class lecture, while the client presentation is considered the culminating activity. The reason for practice or preparation time is to develop skills to a point where they become automatic and internalized so that an individual can draw on these skills when they are needed. In the context of basketball this means reviewing basics such as shooting and dribbling, developing new skills such as defensive movement or rebounding, developing plays which focus on team interactions, and preparing for a particular opponent or situations. In preparing for a project, students must do similar activities. They have to repeat basic skills like report writing or preparing charts and diagrams, they must acquire new skills like the design of an assembly line. They also need to work together as a team where individuals develop designs for components that must fit together into the final product. They must also look outside their own team to prepare for the client presentation.

Table 3 below summarizes the techniques along with the application in basketball and the application in PBL.

Table 3: Practice and Games Techniques

Technique	Basketball	PBL
Repetition	-Repeat basic drills -Review plays	-Examples in class -Homework problems
Permission to fail in practice so that we succeed when it really counts	-Push athletes to the limit during practice -Practices should be harder than games	-Students attempt an analysis then review the solution with the instructor -Final presentation is practiced in front of instructor with much feedback before delivery to client
Uncompromising preparation	-Practice many hours everyday -Attempt to improve everyday -Never be surprised by opponent	-There should never be a question the client asks that the student can't answer -Don't leave any stone unturned
Teach	-Introduce quote of the day to highlight learning opportunity -At the beginning of every practice set three objectives for the day	-Define learning objectives for each class or meeting. -Quote of the day used to link IE subjects to learning opportunities.
Make the practice match the game as much as possible	-Mix teams up in practice so that athletes get use to playing with many players. -Use competition when possible to increase the competitive spirit -Practices are set up so that the handling of unfair situations can be addressed	-The instructor must ask hard questions similar to what the client may ask

Teamwork and Individual performance

In basketball the goal is always the achievement of the team, not the individual. In fact, individual performance is secondary to the team's winning record. In PBL, the team's success is the main goal. The client doesn't care who did which analysis, only that the analysis is complete. In this area, basketball and PBL are very similar.

Table 4 below outlines techniques used in basketball and the parallel technique used in the PBL activity.

Table 4: Teamwork and Individual Performance Techniques

Technique	Basketball	PBL
Reward team achievement	-The success of the team is measured by the team's win/loss record.	-When the client is pleased all team members are rewarded with praise and a good grade
Focus on task at hand	-Concentrate on the next game, not the season record or the tournament championship	-Have a clearly defined goal and make sure all activities support that goal
The team is responsible for individual's work	-If individuals do not achieve goals, the whole team must run suicides. -If the team does succeed, no one is punished.	-If a team member is not contributing, the team is responsible for solving this problem. -Individuals are encouraged to explore novel computational techniques
Attention to detail	-Coach notices who is out of position or not contributing	-Instructor must assess individual contribution through questioning in team meetings
Generous with praise	-Good individual achievements are praised in the context of team achievement. -At the end of practice athletes are asked to give specific positive feedback on other teammate's performance.	-Individual contribution is recognized when it helps the team achieve -Students are asked to give feedback in team meetings on the activities of others on the team.

Individual Feedback for improvement

John Wooden was famous for his definition of success: "Success is peace of mind which is a direct result of self-satisfaction in knowing you made the effort to become the best of which you are capable."[7] Although it is important to achieve something as a team, the reason for both basketball and engineering education is to help individual students achieve all they can. The goal is individual development. To this end each individual deserves attention from the instructor and coach so that growth can be developed and monitored.

Table 5 summarizes the techniques use to enhance individual growth in both basketball and PBL instruction.

Table 5: Individual Feedback for Improvement Techniques

Technique	Basketball	PBL
Track performance	-Record statistics for each individual: Points per game, rebounds per game, -Use stats to set individual goals for growth. -Coaches must know what motivates individual athletes	-Hours spent on the project are tracked to encourage maximum effort. -Getting to know individual students allows for appropriate feedback and motivation techniques.
Immediate feedback	-If an athlete does something incorrectly during practice immediate feedback and correction can occur	-In team meetings, the instructor can catch incorrect application of topics and correction can be made immediately.
Responsibilities matched to abilities	-Individuals on the court are assigned to specific position based on physical attributes, experience, and skills.	-Job applications are filled out at the beginning of the class in order to gather information on skills. Students are assigned to teams by skill set needed for the project.
Individual accountability	-Individual meetings are scheduled with the head coach every two weeks to assess athlete's progress.	-At each team meeting, students are asked to report on their activities for the project. -At the end of the course the instructor writes an individual note to every student outlining their contribution to the team's success.

This framework for thinking about PBL instruction has opened a whole new area of exploration. In some of the parallel areas, experienced PBL instructor will naturally incorporate these good coaching techniques, but in other areas some novel techniques are have been used with good success. Specifically, student accountability has been enhanced by collecting data on time spent on the project. In addition, techniques such as positive feedback of peers and the quote of the day have helped team cohesiveness. The most important aspect has been the idea that the coach or teacher is a role model. Students follow the lead of the instructor when dealing with issues whether they are ethical in nature or regarding individual performance.

Evidence of Technique Success

A survey of students involved in the PBL activity queried individuals on four areas: Team functioning, the usefulness of reporting time spent, the effectiveness of team meetings with the instructor, and general satisfaction with the course and project.

In general students felt their team functioned very well in this project. Of course, it is hard to attribute this to the use of coaching techniques, but it is believed that some of these techniques helped quite a bit. When asked "Did your team function well compared to other teams you have been on?" an overwhelming 96% reported "Yes, it functioned well." Several student comments are included below.

"We had a great time; we were all pretty mellow; everyone always had their best input. I also trusted my teammates do get things done if I asked them to, and they took it in stride to do their best. I had lots of fun with this group."

"…better than I could have asked for"

"Everyone worked hard, and did their fair share which is very important."

Students have to report weekly the time they spent on the project. Included in Figure 1 below is an example of time spent by the eight groups during the Winter quarter of 2009.

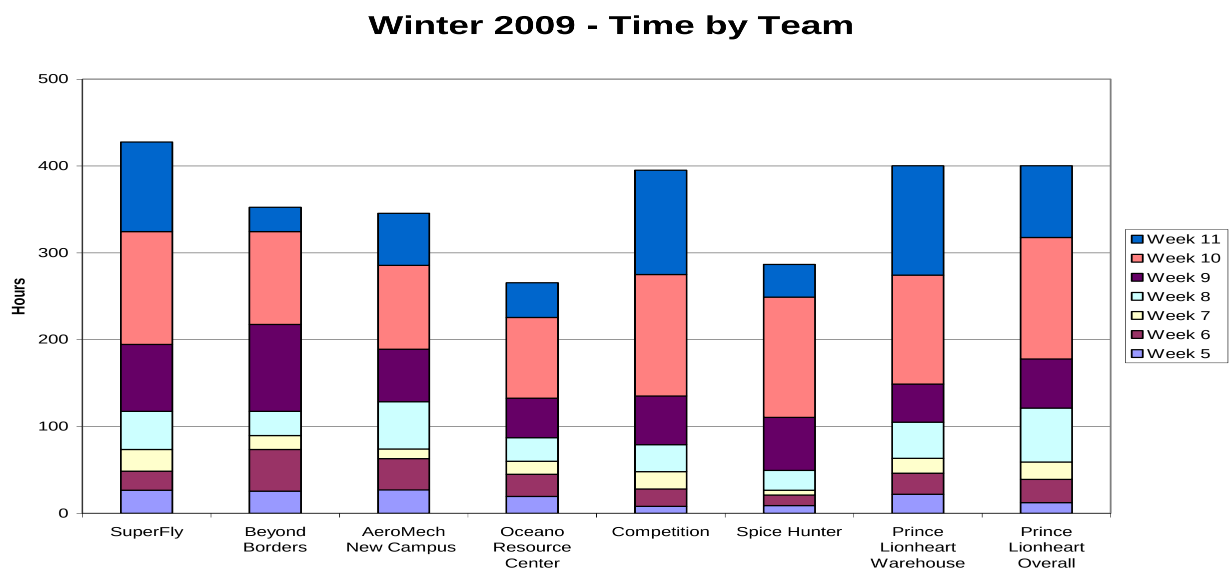

Figure 1: Time Spent by Team by Week for the Eight Projects

When asked, "Did reporting your hours help you work harder on the project?" 69% reported that "Yes, it motivated me to keep working." When asked "Did it help you seeing how much time others were spending on the project?" 38% reported "It motivated me to spend more time on the project." In addition, at the end of the quarter, the students received a faux paycheck based on the hours spent on the project. The paycheck also included a personal note to the student from the instructor. When asked "Was it good to get a paycheck at the end of the class?" 84% said "I liked the personal recognition."

The instructor met with the student groups at least once per week. When asked "Did the individual meetings with the instructor help motivate you on the project?" an overwhelming 96% states "Yes, it was helpful."

One of the objectives of the class defined at the initiation of the project is that the students should be proud of the work done for the client. Eighty-nine percent of the students felt this objective was achieved at a high level and the remaining 11% felt they achieved this objective at an acceptable level. When asked to give feedback on the course, most students gave suggestions for small improvement, but every comment included an observation similar to those below.

"I loved this class, and would take the class again if it was possible just to work on another project! I really liked that I could experience the "real world" by working on real projects. The practice presentation[s] were VERY helpful. We got excellent feedback and let us make the final presentation superb. Also, you were very helpful!! Thanks for all your help!"

"First off, thank you very much for taking the time to write personal letters to everyone. It means a lot that there are professors who care on that level."

Finally the following comment from a client illustrates the value of this activity to all involved.

"I wanted to thank you and them again for their efforts. I know the primary objective is to support the learning experience through the use of a real-world laboratory, but it would be an oversight to ignore the valuable contributions your projects bring to our company. The content of the final report is not the only benefit, I believe the process itself is valuable in that the interactions with the students give our staff an opportunity to consider their daily environment from a different point of view.

"Please consider me and Prince Lionheart boosters of your program, and don't hesitate to reach out if there is ever a way in which we can be helpful."

Conclusions

Incorporating good coaching techniques into PBL instruction has enhanced the outcomes of PBL and will continue to be a good source of new ideas and techniques for this type of education.

Using some specific techniques have lead to success in the PBL activity. Specifically tracking a "time spent" statistic and reporting this back to students has helped motivate performance. In addition, enhanced team building activities like weekly meetings with the instructor and discussion of teamwork performance, helped produce a high functioning team.

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Work In Progress: Model Eliciting Activity for an Undergraduate Thermal Measurements Laboratory

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At Cal Poly, San Luis Obispo our undergraduate engineering education is designed to prepare students for industry. The rise of technology in modern engineering demands a shift in the way undergraduates are prepared for the modern workplace. Engineering problems should focus on the development of analytical models that describe a system. These models, once made, can be used to solve future problems of a similar type. By recreating and inventing some simple engineering problems that can be solved using models, instructors can introduce students to this process to prepare for professional practice.

Model Eliciting Activities (MEAs) are a way to make students think critically about open-ended problems. To ensure that new MEAs are held to a high standard they are subject to six basic principles: model construction, reality, generalizability, self-assessment, model documentation, and effective prototype.

1.) Model Construction: Requires the development of a model or decision algorithm.

2.) Reality: It must be set to a relevant engineering application.

3.) Generalizability: The resulting model should apply to other similar applications.

4.) Self-Assessment: The students must be able to verify the quality of their own work.

5.) Model Documentation: Requires a response or memo describing the model.

6.) Effective Prototype: Involves key engineering concepts that are usable in future work.

With these guidelines MEAs are being introduced into some of the courses in the Mechanical Engineering Department at Cal Poly. Several MEAs have been tried and tested in dynamics, thermodynamics, and mechanical engineering design courses. The next goal is to create an MEA for engineering statistics that includes a hands-on laboratory. The current project focuses on the statistical uncertainty in measuring devices during the process of making steel.

Current MEA Project Description

Steely Dan Steel Manufacturing (fictitious client) has asked Cal Poly to help them choose data acquisition (DAQ) systems to better ensure the consistency of their steel. Steely Dan needs to decide which temperature-measuring DAQ system they should use for each of the steps needed to create steel. Each process has an optimal temperature range with varying allowance for error. The temperature needs to be monitored and averaged continually to ensure consistent results. More expensive DAQ systems are able to take more temperature measurements per second. The student teams will generate a model that takes the desired temperature range and uses it to decide which DAQ system is most appropriate. After checking the model with a DAQ system in the lab, an appropriate DAQ system needs to be found for Steely Dan's blast furnace. Afterwards, Steely Dan needs a memo that describes how they can use the model to choose the necessary DAQ system for each of their other steel processes.

Before the Cal Poly student teams can start they need to be briefed on infrared temperature sensors and how they are used in steel processes. Before the lab, a short quiz assesses their statistics background and includes some open-ended questions about uncertainty.

This MEA will be implemented in a three hour thermal measurements lab in the winter quarter of 2010. The lab has 16 students in their 2^{nd} or 3^{rd} year of college and focuses on hands-on engineering statistics. The main concepts that are being taught in the MEA are the uncertainty associated with finite samples and the inherent uncertainty in temperature measuring devices. Table 1 presents a list of the MEA principles and how the current project satisfies each one.

Table 1: Below is a list of the principles and how the MEA satisfies each one.

Principal of MEA Construction	**Satisfied by:**
Model	The students are creating a system to determine an appropriate DAQ for steel processes.
Reality	High quality steel needs to be made at very specific temperatures for consistency. High-grade infrared temperature sensors are used to monitor these processes.
Generalizability	The model is applied to the blast furnace only but can be used for any of the other steps in the creation of steel.
Self Assessment	The students are forced to check their model against data they collect in the laboratory.
Model Documentation	The student teams will write a memo explaining their model.
Effective Prototype	The concept of statistical uncertainty for finite samples is something that can be seen in many engineering industries.

The goal of MEAs is to promote real-world thinking that students can use as engineering practitioners. Experiences like creating a system model and thinking critically on open-ended problems are essential for success in the workplace. Guiding undergraduates into this type of thinking will better prepare them for the constantly changing field of engineering.

Acknowledgement
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Work in Progress: Student-Created Multimedia Dynamics Example Problems - A Model-Eliciting Activity

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Abstract

Instructors and publishers alike have begun to explore the benefits of online and multimedia content for enhanced learning in a number of engineering courses. Topics in Dynamics can especially benefit from this medium, where videos and simulations can be used to highlight the time-dependent nature of moving systems. Instead of developing such content ourselves, we decided to create a Model-Eliciting Activity (MEA) in which the students were required to develop multi-media example problems. This work in progress describes the basic objectives of the project and a preliminary assessment of its effectiveness through a thematic analysis of student reports and a student survey. We will discuss what students thought was important in multimedia example problems, show samples of what the students developed, and offer recommendations for implementing this MEA.

Course Information

The Multi-Media MEA developed by the authors was used in an introductory, sophomore level Engineering Dynamics course. The course format is three, 50-minute sessions per week in sections of 35 students. Approximately 30 sections are offered each year, serving over 1000 students of various engineering disciplines with three to five different instructors each quarter. A common final exam is administered to all students taking the class. During the fall quarter of 2008 and the winter of 2009, the authors modified the traditional lecture mode of instruction by using more active learning techniques, including collaborative learning and three opened ended projects based on the MEA concept. Supplemental materials included narrated PowerPoint example problems to be viewed by the students prior to class meetings with an attached video clip. It was in this context that students were asked to develop guidelines for making multi-media example problems and to produce an example of their own. The main goal of this project was to promote a deeper understanding of course materials by requiring them to become experts in the material that they were presenting. It was also hoped that the students would better understand and take greater ownership of their own learning.

Student Created Example Problem as a Model-Eliciting Activity

MEAs are developed according to six basic principles[1,2]. Each of these principles was addressed in the creation of the Multi-Media MEA. To satisfy the *Reality Principle*, a fictitious publishing company was the customer. Student teams were required to write a memo discussing important characteristics of multi-media example problems and create one of their own (*Model Documentation Principle*). Additionally, they wrote guidelines or procedures on how other educators should create their own multimedia examples (*Model Construction Principle*). These guidelines were to be shareable by other teams, and had to be relevant for creating other learning materials (*Generalizability Principle*). By examining their own example problem and those of other teams, they could decide if their procedure (or model) was sufficient (*Self Assessment Principle*). Finally, the students should gain some understanding of important concepts or ideas that can be used later in their education or careers (*Effective Prototype Principle*). This might be in the form of metacognition by forcing them to think about their own learning, and/or in the Dynamics principles they address in their multimedia examples.

Results

The Multimedia MEA was presented to students in the sixth week of classes. Students worked in teams of four and were given one week to complete the assignment. For the two quarters, the project was completed by 68 teams. During the fall quarter, the teams were free to select any topic relevant to the class, and the majority chose to make an example problem based on particle dynamics. A typical example involved impact of particles with an accompanied student made video of colliding objects such as basketballs. During the second quarter, the students were requested to make examples pertaining to the Dynamics of rigid bodies. A typical example was the modeling of the lower leg kicking a soccer ball with a video. As part of a comprehensive course survey conducted at the end of the quarter, students were asked whether they felt that the project helped them in understanding course material and whether they found the project interesting and motivating. Student feedback for this project was mixed: 36% of students responded that the project helped them understand the Dynamics material, while 30% disagreed. Responses about project motivation had similar results with 39% of students feeling that the project was motivating and 40% disagreeing. Negative reporting tended to mention the extra workload that students did not feel was relevant to dynamics (e.g., PowerPoint difficulties).

In the memo to the fictitious publishing company, the students were asked to list what they though were important characteristics of multimedia example problems. A partial thematic analysis shows a wide variety of responses from the mundane importance of applying correct principles to the more complex requirement that they be “fun.” The table below lists the six most common cited “important” characteristics from the analysis of 27 of the 68 submitted reports.

Important Characteristic of Multi-Media Example Problem	**% Reported**
Effective use of Visuals (Both Video and Figures) for “Visual Learners”	70
The use of a “Real- World” Problem (often cited to make it interesting and fun)	67
Solution should be presented in a linear, systematic or logical fashion	52
Level of complexity or difficulty should be appropriate	41
Notation should be consistent between examples and with text	26
Examples should be “Clear”	26
Advanced or important concepts should be explained verbally and in detail.	26

Conclusions and Future Directions

The analysis of the memorandums was encouraging. It showed that the students had an awareness of what was important in their own and others learning. It was a little disappointing that the students did not find the exercise very motivating or overly valuable for their understanding of Dynamics. A more complete thematic analysis of all submitted work is ongoing. In general the authors found that using this project in conjunction with other MEA’s in an active-learning based Dynamics course has led to gains by the students in conceptual understanding and on the more procedurally based common final exam.

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A High Frequency Transceiver for Amateur Radio Using Software Defined Radio

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Abstract

This paper describes a Software Defined Radio (SDR) based High Frequency (HF) transceiver for amateur radio that was designed to fulfill the senior design project requirement in Electrical and Computer Engineering at California State University, Northridge. The uniqueness of the SDR approach is that most of the hardware components found in a conventional transceiver are replaced by software. This results in near-ideal filters and a reduction in overall physical size. In addition, any improvements or changes to the SDR transceiver would only require a software upgrade as opposed to a labor-intensive redesign of the hardware version of the transceiver itself.

The paper will describe the specifications of the HF transceiver and the various modes of operation. This will be followed by a detailed explanation of how all these different components come together in one software package.

Although this started out as a senior project designed to teach the technical aspects of engineering, the scope quickly expanded to encompass many facets of a real engineering project: time management, written and oral communications, and working cohesively within a multidisciplinary team. This paper will elucidate the myriad of challenges the team encountered and overcame.

I. Introduction

This paper details the senior design team project by students at California State University, Northridge (CSUN). The purpose of the project was to build a software defined radio (SDR) based high frequency (HF) amateur radio transceiver. The twelve month project included both the technical and project management aspects commonly found in a real-life design project. Electrical and computer engineering undergraduates at CSUN are required to complete a group project as part of their senior design course. This project is one of the activities that are used to demonstrate that our graduates have achieved the following outcomes:

- 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
- an ability to function on multidisciplinary teams
- an ability to communicate effectively

While all of the projects assigned as part of senior design attempt to demonstrate these outcomes, our preliminary assessment shows evidence that the unique aspects of this project provided deeper challenges and opportunities to the students. The challenges of the projects motivated students to higher levels of performance in the required outcomes while working with SDR gave them the opportunity to realize their designs within the time frame of the course.

Section II of the paper will provide background information on SDR. Section III will describe the project itself and the various components implemented. Section IV of the paper will provide the results of the project and the different aspects learned through the project. Section V discusses our assessment of the educational outcomes listed above. Finally, Section VI will present the summary and conclusions.

II. Background

The foundation of this project is software defined radio. The main idea behind SDR is to take signal processing schemes traditionally done in hardware and achieve the same results with software.

Although the eventual goal of SDR is to move all software signal processing as close to the antenna as possible, there was a front-end device used immediately after the antenna in this project: the universal software radio peripheral (USRP). For receiving radio signals, the USRP provides analog to digital convertors (ADCs), the required frequency down conversion and the decimation of the digital samples needed prior to sending the signal to the host computer1. The process is reversed on transmission. The USRP digitally up converts the signal to the desired frequency before digital to analog convertors (DACs) convert the signal back to analog and send the signal back out to the antenna1.

Figure 1 details a traditional hardware receiver. Figure 2 depicts an SDR system. In this case, the receiver front-end is merely a filter and gain stage while the software in the host computer replaces the balance of the receiver after analog to digital conversion. As outlined in Figure 3, the USRP provides the analog to digital conversion and frequency down conversion.

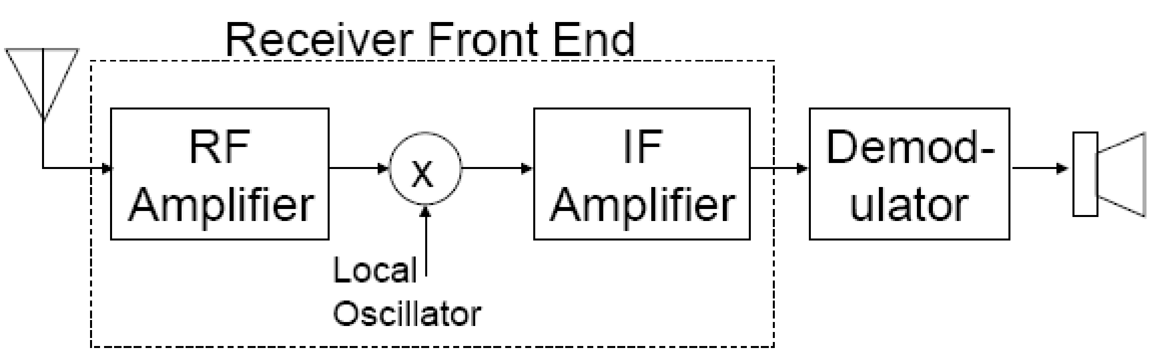

Figure 1. Traditional Hardware Receiver

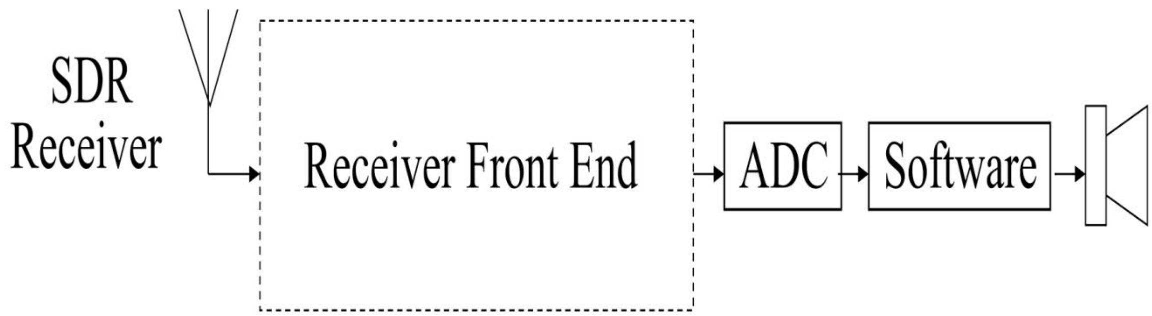

Figure 2. SDR Receiver

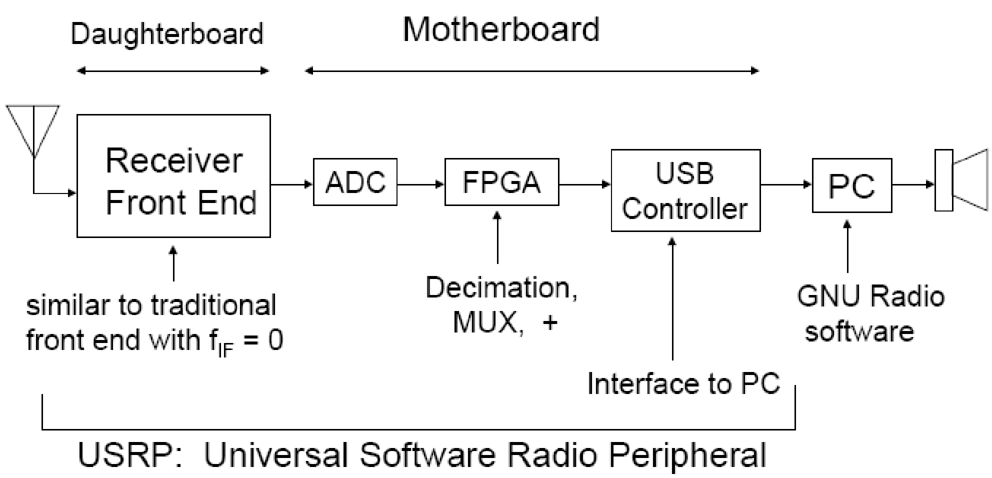

Figure 3. SDR Receiver with USRP

For the SDR HF transceiver, the software is the brain of this entire transceiver operation. The bulk of the software for this project was done with GNU Radio, a "free software development toolkit" which eventually led to the creation of the USRP2. GNU Radio has an extensive library of code blocks which can modulate, demodulate, filter and process a signal in the desired manner.

Besides utilizing GNU Radio, much of the coding – especially for the Graphical User Interface (GUI) – was done entirely from scratch using the Python programming language. Since GNU Radio is written in Python, it is only reasonable to write the additional code in Python to ensure maximum compatibility.

There are numerous benefits to implementing a transceiver that uses SDR. The first benefit is that filters that would be impractical or impossible to implement in a hardware system can now be easily implemented with SDR at the expense of some processing power. However, the resounding theme and the main benefit of SDR is flexibility. With a single receiver front-end, software can be written to transmit and receive AM, FM, CW (Morse code), or any other mode. This realization can be achieved without ever having to alter the hardware in any way. As soon as a new block of code is written, it can be implemented and tested immediately. The flexibility to fine-tune and the ability to make on-the-fly alterations are astounding and practically unheard of in the hardware industry.

One may be able to imagine the difficulty, not to mention financial restrictions, to make changes or updates to an already existing hardware system. With software defined radio, the system can be changed to adapt to current needs quickly and inexpensively.

The impetus behind this project should be mentioned here. This project was funded and made possible by Edwards Air Force Base. EAFB and CSUN have been partnered since 2003 in an effort to increase and maintain the number of students that work or intern at EAFB as well as increase interests in complex projects such as this. Thanks to that partnership, the students have gained and will continue to gain invaluable knowledge and experience that will help them succeed in the workforce.

III. Project Description

Amateur radio transceivers are devices used by the over 1 million hobbyists around the world to transmit and receive signals. Many different transceiver models are available, ranging in price from several hundred dollars to well over $2000. The purpose of this project is to create a transceiver using SDR with comparable performance to a high-end hardware transceiver.

As an integral part of an improved senior design course, students taking part in this project were exposed to a near real life engineering world. The CSUN faculty acted as management/customers, setting time and resource limitations on the students. The students were required to give weekly oral presentations on their progress and problems encountered. The faculty offered guidance to possible solutions, but emphasized real constraints on solutions, including cost, lead time, reliability, manufacturability and team time investment.

The SDR transceiver was designed with the following requirements:

1. The SDR Transceiver operates in the high frequency (HF) amateur radio band from 1.8 to 29.7 MHz.
2. The transceiver has a GUI that will be understandable to amateur radio operators.
3. The GUI has the following information for the operator:
    - Received signal strength
    - Transmitted signal power
    - Received bandwidth
    - Mode
    - Volume
    - Transmit frequency
    - Receive frequency

- RF gain/attenuation
- Display of frequency in use plus surrounding frequencies

4. The transceiver transmits and receives in the following modes.
   - Amplitude Modulation (AM)
   - Frequency Modulation (FM)
   - Single Sideband (both USB and LSB)
   - Continuous Wave (CW, or Morse Code)
   - Digital Modulation
5. The transceiver conforms to current FCC regulations regarding:
   - Transmitted Bandwidth
   - Harmonic suppression
   - Spurious emissions
6. An instruction manual covering installation (software) and operation is provided.
7. The following transceivers were used as inspirations for design features and specification comparisons:
   - ICOM IC7700, IC7800
   - Yaesu FT-1000D, FTDX-9000
   - Kenwood TS-2000

IV. Project Outcomes and Results

Technical Accomplishments

The project consisted of specific requirements and modulation schemes that were researched, analyzed mathematically, and implemented into a working system that would be distributed freely under the GNU General Public License. The project software and related items are hosted on SourceForge, a website dedicated to source code repository and open source software projects.

Although five modulation schemes were mentioned in Section III, digital modulation was ultimately scrapped due to time constraints. The team decided it was best to have four complete modes rather than several incomplete modes at the end.

AM pioneered the architecture used throughout the rest of the project for implementing the various modulation modes. It was also the first mode implemented into the GUI with the required applications, such as power meter and S-meter. Because the design of the AM section was very thorough, this implementation process was utilized in all subsequent modes.

A figure of the main GUI window is shown in Figure 4 below. This is the first item the user sees when starting up the software. The upper portion allows the user to select a specific mode via a drop-down box. After choosing the desired mode, the user must click on the select button to start that particular mode. Below the mode selection is the parameter display. A bar gauge functions as the output power meter on transmit and the signal strength, or S-meter, on receive. The original intent was to design two discrete gauges, but after reviewing the hardware transceivers available, the team decided to implement one gauge with separate power and S-meter labels – a common feature in the hardware transceivers.

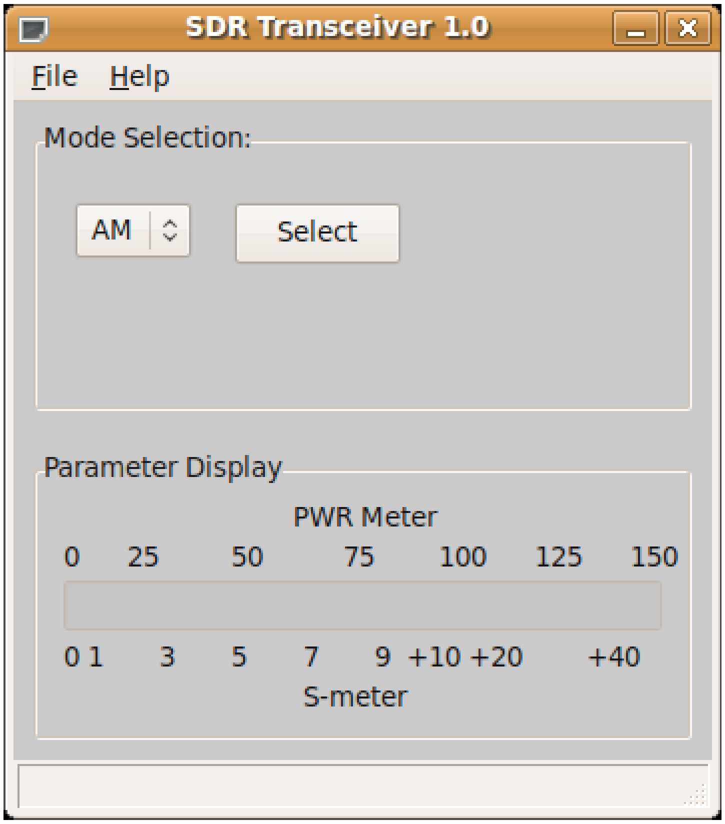

Figure 4. SDR Transceiver Main GUI Window

After the user confirms the selected mode, a new window will appear alongside the main GUI window. Many of the features shown in this AM example appear in other modes. However, some are tailored to have more or fewer features. As examples, FM contains the squelch control and CW only contains one receiver channel.

It is important to note here that only one mode may be active at any time. If a mode is already running, the selection of another mode is restricted because resources such as the audio driver are already being dedicated to the first mode. In order to select another mode, the user must first explicitly close the currently running mode.

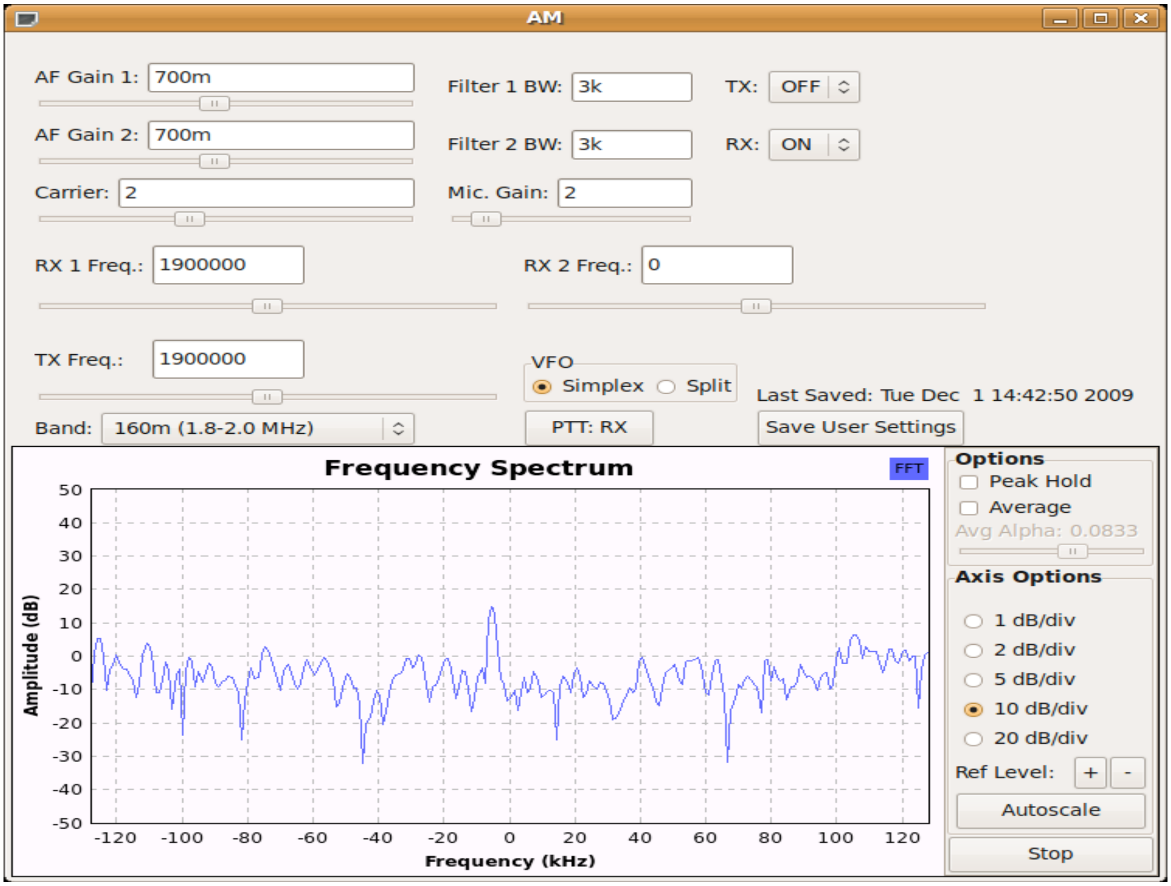

Figure 5. AM Mode Window

As shown in Figure 5 above, the user has control over many features and functions. In AM and SSB, there are two receiver channels; the user is able to listen on two separate frequencies (one channel in one speaker, the second channel on the other). Because of this, there are two audio frequency (AF) gain controls, which are the receiver volume controls. To the right of the AF Gains are the receive filter bandwidth controls. They control the filter cutoff frequency for the two receiver channels. The bandwidth is limited to a maximum of 4 kHz by the sampling rate used in the filter sections.

Below the receiver controls are the carrier and microphone gains. These two controls set the power output of the transmitter. The carrier control sets the carrier level while the microphone gain sets the modulation level.

In the Variable Frequency Oscillator (VFO) section, the two choices are simplex or split. In simplex mode, the receiver and transmitter frequencies are "locked" such that moving one will also move the other. In split mode, the receiver and transmitter frequencies may be moved independently of one another. When the second receiver – designated RX 2 Freq. – is set to zero, it represents an offset of zero such that the speakers will only play the main receiver frequency channel.

The PTT button stands for Push-To-Talk, and by default it is on receive. Clicking on the button will have the text change to "PTT: TX," signaling the user that the mode is now transmitting.

The two drop-down boxes on the top-right of the window allows more functions such as both receiver and transmitter off, or both on, should there be a desire to implement full-duplex operations for future teams. On the lower-left, a drop-down box displays all the bands allowed by FCC regulations in the HF range.

Because a major objective of this project is to emulate a program that would be used commercially by many people around the world, a save feature was implemented. The "Save User Settings" button is able to store every feature the user has control over into an external file. A timestamp of when the user last saved the settings is displayed on both the mode window as well as the external file for reference. This function was created for ease of use and provides both a friendlier and faster way to use the software.

The SDR HF Transceiver was completed and tested to specifications on time in November 2009. Using a receiver pre-amplifier and a 140 watt transmit power amplifier provided by faculty, the transceiver was used to carry out a number of contacts. Stations in Seattle, Washington, Fairbanks, Alaska and Mexico City were contacted and signal reports received. Subjective assessments rated the signal as clear and understandable.

Lessons Learned

Many technical lessons were learned through the SDR Transceiver project. The first is being able to go from designing, through implementation, to debugging and troubleshooting. The technical challenges include having to translate the theories learned in classroom settings regarding the various modes into software, which is not always a one-to-one translation. The implementation process taught the team how to link the software code to the hardware, such as the USRP and the antenna, and vice versa. This often resulted in errors and bugs that the team had to troubleshoot before patching the system to resolve the issues.

The non-technical lessons learned are equally, if not more, important than the technical lessons. The first is project management, which proved to be crucial during the twelve months for the project. Good project management includes balancing every member's time and schedule as well as laying out a timeline of what needs to be done in a timely manner. There are many components in the project, and managing every member's time became more and more crucial as time went on. Most of the members from the team are close to graduation, thus time management included other facets of the group's lives, such as school and work. Having good project management keeps everybody on pace on what and when something needs to be accomplished. Furthermore, this provides a list of goals that the team is ultimately moving towards. Being able to see what components still need to be completed as time goes on keeps everyone focused and looking ahead.

Time management was facilitated by the use of Gantt charts to keep a timeline of what needed to be completed within a certain amount of time. To further keep every task on schedule, a weekly meeting was established to brief the professors on what has transpired over the past week and what tasks would be worked on the in following week.

Working in a real-life setting meant dealing with rules and regulations. In the case of the SDR Transceiver project, the team had to constantly deal with FCC rules and regulations – examples being sideband suppression and bandwidths allowed.

Another important lesson learned was documentation. However, the lesson was not just documentation, but *good* documentation. This includes the software code, the schematics, and reasons for approaching an issue in certain ways. Good documentation keeps everyone else in the group, as well people outside the group, aware and knowledgeable of every aspect of the project.

Lastly, the concept of regression testing was monumental throughout this project. The concept of regression testing is to re-test the entire system every time a new component is inserted into the overall system. The reason for doing so is because there could be unintended results when a new part is introduced into the system – often deleterious to the overall progress of the project.

The SDR Transceiver project required students to be proficient in both electrical and computer engineering fields. The reason is that students must have a background in programming and communications to implement all the features of this project. Every member on the team is an Electrical Engineering major. At CSUN, electrical engineering majors only take one programming course, which made the design and implementation of the features and functions difficult. It is because of this, a new programming language – Python – had to be learned in a relatively short amount of time.

Comparing the SDR Transceiver to the hardware transceivers sold in the consumer market, the SDR Transceiver has several advantages. The first is financially, as the SDR Transceiver only requires the purchase of the USRP (both software and hardware require an antenna, so it is not counted in this comparison). At $700, the USRP is very cheap compared to the transceivers sold in the market.

Another distinct advantage of the SDR Transceiver is achieving results not realizable, or at the very least, not practical, in hardware transceivers. For instance, in the SDR Transceiver the filter is set to 380th order – resulting in near-ideal responses. Such a high order is simply not realizable or financially feasible in hardware transceivers.

Other advantages were made apparent as the SDR Transceiver was being tested. It met or exceeded all specifications and compared favorably with high-end amateur transceivers. For example, Part 97 of the FCC regulations stipulates that the unwanted sideband suppression should exceed 50 dB3. The Yaesu FT-1000D has 55 dB of unwanted sideband suppression4.

The SDR Transceiver achieves 70 dB of suppression. Another example is 3rd order intermodulation distortion (IMD), a standard measure of how much distortion in present in a sideband signal. The FT-1000D has 3rd order distortion products 36 dB down from the main signal, while the SDR Transceiver was measured at 35 dB down4.

The last main advantage is the flexibility discussed throughout the entirety of this paper. The user can change settings instantly without having to solder or change any hardware components in the process. Furthermore, troubleshooting and debugging is several times easier because any changes could be tested right away. Furthermore, the concept of the SDR Transceiver is completely built on the concept of modular design. After selecting the mode from the main GUI, the new mode window is started as a new process separate from the main GUI. The only tie between the two processes is the S-meter and power meter data from the mode window to the main GUI window. This makes the design of additional modes, such as digital modulation, an easy addition into the software because each mode has its own Python file. Simply code the new mode, put the file in the same directory as the GUI file, follow the code used to initiate a new process for other modes like AM or SSB, and the new digital modulation has been integrated into the software system. Furthermore, due to the modular design of making the modes entirely separate processes from the main GUI, crashing a specific mode will not crash the entire software program.

V. Assessment of Educational Outcomes

Senior design at CSUN is used to demonstrate that our graduates have achieved the following outcomes:

- 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
- an ability to function on multidisciplinary teams
- an ability to communicate effectively

The transceiver project described in this paper was part of a Design Clinic sponsored by Edwards Air Force Base (EAFB). This gave students the opportunity to work on a real world problem with realistic constraints. The requirements presented to the students included the need to create a system that was comparable to existing commercial amateur radio transceivers in terms of performance and operation along with the need to operate within FCC regulations.

The team consisted of six electrical and computer engineering students. The aspects of the project covered several of the disciplines within electrical and computer engineering including communications, signal processing, electronics, antenna design, digital systems, and software. This provided an excellent experience for students to experience the challenges of functioning on a multidisciplinary team.

All senior design students are required to submit both oral and written reports on their projects throughout the course. The funding provided by the EAFB design clinic gave the faculty advisors on this project the opportunity to enrich the communications portion of this course. Students were required to give oral progress reports on a weekly basis. The reports were critiqued by three faculty. Two of the faculty advisors have extensive industry experience. This exposed students to many of the presentation styles currently used in industry. In addition to the standard report on their project, the student participants were also required to write a paper for submission to a conference.

The assessment of this project was informal. However, even without a formal assessment, evidence was collected to indicate that the projects and the format in which they were offered did improve the ability of our graduates to demonstrate the outcomes listed above. The following indications were noted and will be measured formally in the coming year:

- Faculty advisors observed a noted improvement in presentation skills of the students
- Representatives from industry attending student presentations indicated that students made better presentations than generally expected from new graduates and were impressed with the technical level of their work
- Industry representatives also commented on the excellent teamwork
- As compared to other senior design students, the presentations were notably better
- Student participants indicated their satisfaction with working on the project even though they realized it was more work than other senior projects
- Student enthusiasm for the project was evident from their dedication and hard work
- Faculty advisors noted that the use of SDR enabled the students to complete more complex and interesting projects in the communications area.

One negative aspect of this project was the amount of faculty support that it required was well above the level that is normally available to senior design students. In this case the support was possible due to the funding available from the EAFB Design Clinic and the faculty interest in SDR. The department is investigating ways to implement the model used in a more cost effective manner.

VI. Summary and Conclusions

This senior design team project by the students at the California State University, Northridge, focused on the concept of Software Defined Radio. Funded by Edwards Air Force Base, Software Defined Radio aims to lessen the number of hardware components, replacing them with software instead. Being able to upgrade or patch via software, rather than redesigning the hardware system from scratch, has enormous benefits in today's world of digital technology.

This project amalgamated aspects of a real-life design project not normally found in classroom settings. The interdisciplinary nature of the project meant the students have had exposure to both the analog and digital sides of electrical and computer engineering. The main lesson learned through this project is how to take everything learned in classrooms and apply them in a development setting with project and time management, from budgeting every member's time to ensuring the project is completed on schedule.

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Software Defined Radio
Communication Link for an Unmanned Aerial Vehicle

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Abstract

This paper describes a Senior Design Project at California State University Northridge to design and implement a communication link between a ground station and an Unmanned Aerial Vehicle (UAV) using software defined radio (SDR). Specifically, this project focused on utilizing and extending an open source software library known as GNU Radio to design a ground station, communication link, and on board controller. The ground station is capable of interrogating the on board controller for telemetry data, images from the plane, frequency spectra of the communications link as seen from the plane, and GPS data. All of the commands and data are processed through an intuitive graphical user interface. The on board controller has been designed to function as close to an embedded application as possible to perform the various commands that may be sent from the ground station. The on board controller has a "phone home" feature that was designed to place the plane in a default mode and to attempt to reestablish communication with the ground if the connection is lost for any reason.

The use of SDR for the communication link replaces a comparable hardware scheme, allowing the link to change modes and frequency as needed. Furthermore, the use of software defined radio has allowed issues of size and weight restrictions on the plane to be overcome, achieving better communications capability than would be realizable with a traditional all-hardware approach.

I. Introduction

This paper describes a senior design project completed by students at California State University, Northridge. The goal of the project was to design and implement a communications link between an unmanned aerial vehicle (UAV) and ground station using software defined radio (SDR). At the start of this project the question was posed "how closely could a hardware based communication link be implemented using software?" As will be shown in this paper, the answer is "completely".

Electrical and computer engineering undergraduates at CSUN are required to complete a group project as part of their senior design course. This project is one of the activities that are used to demonstrate that our graduates have achieved the following outcomes:

- 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
- an ability to function on multidisciplinary teams

• an ability to communicate effectively

While all of the projects assigned as part of senior design attempt to demonstrate these outcomes, our preliminary assessment shows evidence that the unique aspects of this project provided deeper challenges and opportunities to the students. The challenges of the projects motivated students to higher levels of performance in the required outcomes, while working with SDR gave them the opportunity to realize their designs within the time frame of the course.

Section II of this paper will discuss the background of software defined radio (SDR) as well as some hardware essential to implementing an SDR system. Section III will outline the requirements of the design project given at the beginning of the year. It will go on to discuss the approach used to complete the project on both the hardware and software sides, as well as integrating and testing the final design. Section IV will discuss the results of the project and discuss some of the interdisciplinary and soft skills that were learned. It will also focus on the pitfalls encountered during the project and further improvements that could be made. Section V discusses our assessment of the educational outcomes listed above. Finally, Section VI will present the summary and conclusions.

II. Background

This project was based on the concept of software defined radio. SDR essentially takes the hardware components usually found in communication systems and implements their functions in software. On reception, software processes real signals converted into digital form just after the antenna and calculates the intelligence riding on them. On transmission, the software generates the outgoing signal and this is converted into analog form and amplified before being sent out to the antenna.

The software used in this project was GNU Radio. GNU Radio is open source software and can be downloaded from www.gnuradio.org. The software is operating system (OS) independent. However, for this project all code development, implementation, and testing was done in Ubuntu, a Linux distribution. The reason for this was basically ease of implementation; most of the developers use Ubuntu to develop this software library and on the website it was documented that this would be the easiest way to get the code initially up and running. The second reason for going with Linux over a Windows or Mac OS was that the group wanted the freedom to modify programs to suit the project and using an open source OS allowed them to accomplish this.

SDR can replace most of the components found in hardware communication systems however it cannot replace everything. It requires getting the signal from the air into the computer in a format that the computer understands. This task is accomplished using a piece of hardware known as a Universal Software Radio Peripheral (USRP). The USRP consists of an antenna, an analog frequency up/down convertor, a set of analog to digital converters (ADCs), digital to analog convertors (DACs), and a field programmable gate array (FPGA). The USRP can accept different boards called daughter boards, which contain the analog frequency up/down convertors operating in different frequency bands. When the USRP is in receive mode it will down convert the signal, digitize it and decimate it in the FPGA to a sample rate that can be readily passed through a universal serial bus (USB) to a computer. When the USRP is transmitting, the FPGA will interpolate the signal to the sample rate required by the DAC to convert the digital signal back to analog. The analog up convertor brings the signal to the frequency specified so that it can be transmitted.

For this project, other pieces of hardware were either acquired or built to provide information about the UAV, including a camera, GPS, and battery voltage and temperature sensors. These will be discussed later in the paper.

Since the purpose of the project was to build a communication link, the actual UAV will not be discussed, as it was assumed at the start of the project that the plane was not a consideration. Edwards Air Force Base (EAFB) funded the project throughout this past year. EAFB and the Department of Electrical and Computer Engineering at California State University Northridge (CSUN) have had a close working relationship. Due to the complexity of this project, as well as the cost of some of the hardware, it is doubtful that the project would have progressed as far as it did had it not been for their contribution.

III. Project Description

Environment

The project was conducted as if in a real job environment where students had to present weekly oral reports on what was accomplished, problems that were encountered and what was planned to be accomplished in the following week. Professors acted as management, setting real world limits on possible solutions to the problems encountered.

Requirements

The requirements for the project are shown below:

- Data link between UAV and ground station
- Link will use 420-450 MHz UHF amateur radio band.
- Bandwidth and mode will conform to Federal Communications Commission (FCC) rules.
- Air unit completely self-contained using SDR.
- Ground unit also uses SDR.
- Maximum range (at given bit error rate) to be determined by group.
- Link will be bi-directional
- Uplink to UAV will be commands to interrogate UAV for data.
- Downlink will include:
    - o Images from on-board camera
    - o GPS vehicle location information
    - o Vehicle status information (battery voltage, temperature, etc.)
- Uplink commands will be capable of controlling link frequency, bandwidth, data rate and mode.

- “Phone home” feature will return UAV transceiver to default mode, frequency, bandwidth and data rate in the event of loss of link.
- Link will be pinged periodically to assess link health.
- Ground Station will have a graphical user interface (GUI) to display:
    - Raw downlink data
    - Link health
    - Signal strength
    - Images from UAV
    - UAV location (latitude/longitude or map)
    - Interrogation command controls
    - Command status (answered, ignored or garbled)
    - Panoramic display of channel bandwidth to identify possible interfering signals

At the onset of the project it was necessary to develop a plan and a timeline for accomplishing these specifications. It was decided that the project should first be broken down into three functional areas called the ground station, the link, and the onboard controller. These three areas were further broken down into subtasks that could be handled by individual group members. For example, the onboard system was broken down into telemetry sensors, GPS, image capture, spectrum display, and the actual controller itself. Once these tasks were determined, the project manager assigned tasks to the group members and they in turn decided on an approach to accomplish the tasks.

Telemetry Sensors

The UAV was required to have the ability to send telemetry of the onboard temperature and battery voltage to the ground station. During the design phase, various methods were drafted and considered to accomplish this portion of the project. One such method discussed was to use the FPGA on the USRP. Although this could have been achieved, it was determined that this method would use too many personnel resources and the probability of success in the given time frame was low. Another method discussed was the use of the analog to digital converters on board the USRP, this idea was quickly rejected by the faculty advisors due to the limited quantity in the USRP and the project’s dependence on them. The chosen method used a 555 timer in the monostable or “one shot” mode to produce a unique pulse width for a give temperature or battery voltage. This method was chosen since it had the most educational value, it is inexpensive, and it seemed reasonably realistic given the time frame.

Figure 1 shows the basic topology of the telemetry circuit.

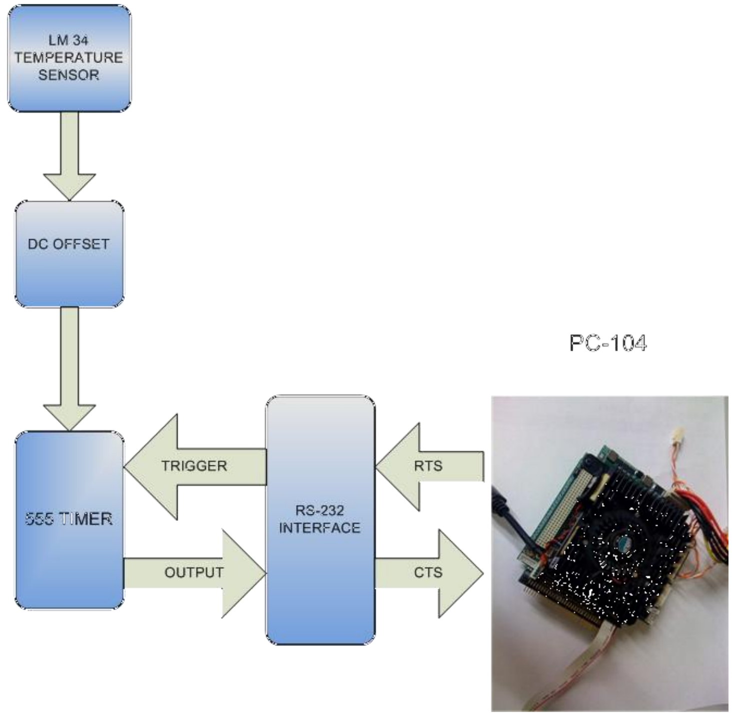

Figure 1. Topology of Telemetry Circuit

Temperature and battery voltage curves were plotted versus the resulting pulse width and the equations from these curves were derived using EXCEL. The resulting equations were programmed in the onboard computer where the telemetry parameters were calculated and stored, ready to be transmitted to the ground station.

Many obstacles and components necessary to the design of this circuit were overlooked but quickly dealt with or added. These include a simple voltage regulator to insure a constant power supply to the 555 timer (highly dependent on supply voltage) and the interface between the telemetry sensor circuitry and the RS-232 port.

Data Link

The data link requirement was to transport information and commands between a ground station and a UAV using USRPs and a digital modulation scheme. This scheme had to meet or exceed a bit error rate of 10^{-5} at a range of 3.3 miles with the given power and bandwidth available. The power available from the daughterboard is 20 mW and the bandwidth allowed by the FCC is 50 KHz. With these requirements in mind and along with the available implemented modulation schemes in GNU Radio, differential binary phase shift keying (DBPSK) was the only scheme that could conform to these specifications reliably. Other schemes such as quadrature amplitude modulation (QAM), frequency shift keying (FSK), eight level phase shift keying (8-PSK), and others were available but unrealizable due to improper implementation in GNU Radio or unreliable behavior. Time limitations and reliability pointed to DPSK, and more specifically differential binary phase shift keying (DBPSK), as the only mode that met and exceeded the required performance measures.

The link also required a wireless communications protocol. While there were many protocols already designed and in use, a unique, new protocol was designed specifically for the application of a point-to-point duplex communication using selective retransmit of corrupted packets.

User Interface

The main interface to the user was a graphical user interface (GUI) for the ground station. It was decided to follow a standard control hierarchy to manage this interface, called a model-viewcontroller (MVC). A MVC is basically three separate entities used to control the entire GUI application, from what the user sees and can manipulate, to the back end controller that is handling the data and managing the system calls for the GUI[1, 2, 3] (see Figure 2). For the ground station, the view sets up the basic layout of everything on the screen. The model acts as the go between for the user and the controller. The controller handles majority of the work. This unit is responsible for managing the ground controlled communication link, declaring when to update the GUI, keeping track of all of the data that is being displayed on the GUI, and handling errors from the underlying systems. One major task of the controller is to manage the communication link with the UAV.

UAV Controller

The UAV also has a completely custom controller that is set up to run as an embedded system on an Advantech PCM-3380[4]. This is a PC/104 standard, single board computer (SBC) with a 1.4 GHz Intel Celeron processor. The controller for the UAV was set up in such a way that it continually waits for a message from the ground, and upon arrival, it decodes and executes the command, and then sends the results back to the ground. The controller is set up to be started during the boot process of the operating system with an installer. To ensure that the controller onboard the UAV does not suffer an unrecoverable fault, a watchdog system was setup to restart the controller upon catastrophic failure.

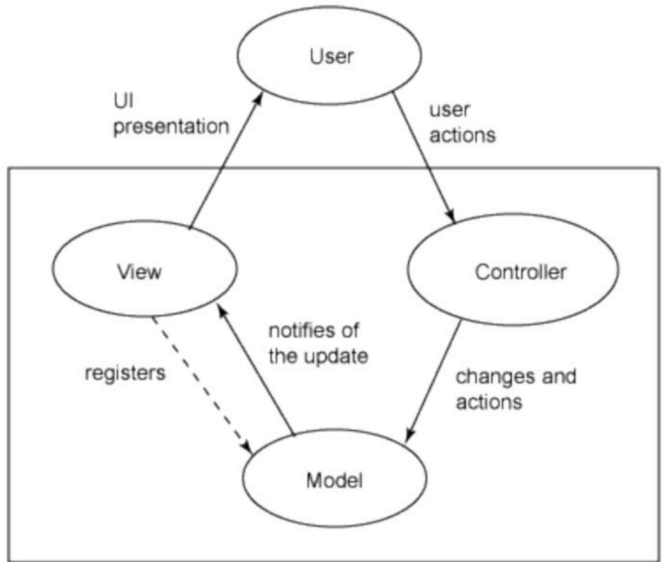

Figure 2[3]

IV. Project Outcomes and Results

The project met all of the major requirements specified at the beginning of the year. The UAV project provides a bi-directional communications link between an on-board computer system in a UAV and ground station software running on a laptop computer on the 420-450MHz UHF amateur radio band using Software Defined Radio. The on-board controller is fully selfcontained and operates without user intervention. It responds to the various commands that are sent from the ground station, including requesting images, radio spectrum data, and sensor data including battery voltage, temperature, and GPS information. The UAV has met the requirements of being able to change frequencies as well as digital modulation schemes. The UAV supports DBPSK and quadrature phase shift keying (QPSK). It also includes a "phone home" feature, where the UAV will automatically return to default settings in the event that ability to communicate with the ground station is lost for a length of time specified by the ground controller.

The link exceeds the specification by a wide margin. Given the bit error rate (BER) versus signal to noise ratio (SNR) relationship for DBPSK, the given signal power and the USRP noise figure, the link equation yields a realizable line of sight range of 25 miles for a 10^{-5} BER or better. Laboratory testing has confirmed this and range testing has yielded results commensurate with this.

The most important lesson learned in this project is setting realisitic, sufficiently short term goals. Everyone has a tendency to overestimate what they can accomplish and grossly underestimate the amount of time it will take. Students are notorious for procrastinating. Given a full academic year to complete a project, the most diligent students would probably start to get real work done around the half-way point. Most would start even later. This leads to staying up all night for a few weeks straight, rushing to put everything together, and not meeting all the project requirements. This can be avoided by having weekly goals that must be met.

Procrastination is minimized, and students stay up the night before to meet the goal. The only caveat is that goals must be significant enough to make progress towards completing the project as a whole.

Choosing appropriate goals proved to be a challenge. The process of choosing goals was closely coupled with the overall design of the system. Project management has several stages, including initial research, planning, design, implementation, testing, verification, and completion. Traditionally, these stages are thought of as occurring sequentially and only happening once in a project's life cycle. Instead of following this structure, the group went through each stage weekly. It is quite unrealistic to believe that the group could complete the entire design of this system in one phase. It would have required them to define each and every detail about the implementation of every subsystem, as well as how each subsystem would work together. It is possible to do, but if one piece of the system did not behave as expected, the entire project would be at risk of being derailed. A minor oversight in research or planning could be the cause a complete redesign, which could take at best, a few weeks, and at worst, months.

The project taught students to work with a timeline. The major goal was to finish the project by the due date. The design approach was a bit difficult at first because with any project there are several ways to solve something. Once a design approach was in place, everyone was then able to work together in pursuit of finishing the project. Whatever problem or hold up of the project came up, students had to be able to find solutions and move the project forward. At times the dead line for the project seemed very far off and time seemed sufficient, but it was soon discovered that the due date was right around the corner.

Being part of a project of this magnitude brings several outcomes in students' learning. One of the things learned was the ability to communicate and work with others. Many times in groups, students have a tough time working with one another because of difference of opinions or difference of technical background. The students also had to communicate effectively with faculty. Not only did faculty act as upper management on the project, they were also available to help students with questions they might have and with advice on conducting the presentations themselves. This formula was successful because it gave the opportunity for a student to experience what an engineer deals with in the real world.

The project had an interdisciplinary nature to it. SDR was new to students. Designing SDR systems requires knowledge in software, digital signal processing, electronics, and communications systems.

The project exposed students to things they might not have been familiar with such as Python programming. The project required a lot of programming code. Python is a programming language that was unfamiliar to most. Those who were unfamiliar learned extensive programming and it is a skill that can be used in the future. Numerous of hours went into building the software components needed for the project. Not all the components necessary were available in GNU Radio and therefore had to be created from scratch. Problems of different magnitudes were uncovered as the project moved forward and every one had to find solutions and get past these obstacles.

The project also taught how to design a circuit when it was needed. A circuit that would be able to read temperature and battery voltage was necessary for the project. Students learned to design the circuit and then be able to prototype and test the finished circuit.

Finally, the project also taught students to become better researchers. The project brought on many problems that were in wholly unfamiliar subjects. Research was important because it yielded more knowledge of the problem at hand and helped in understanding things better. This is vital because design has a lot of alternatives; the more knowledge the engineer has about the problem at hand, the better the design approach will be. The telemetry sensor circuit is one example. It can be designed in many ways but the research allowed for the easier and better way of realizing it.

V. Assessment of Educational Outcomes

Senior design at CSUN is used to demonstrate that our graduates have achieved the following outcomes:

- 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
- an ability to function on multidisciplinary teams
- an ability to communicate effectively

The UAV project was part of a Design Clinic sponsored by Edwards Air Force Base (EAFB). This gave students the opportunity to work on a real world problem with realistic constraints. The requirements presented to the students included the physical and environmental constraints of designing a system to fly in a small UAV along with the need to operate within FCC regulations.

The team consisted of six electrical and computer engineering students. The aspects of the project covered several of the disciplines within electrical and computer engineering including communications, signal processing, electronics, antenna design, digital systems, and software. This provided an excellent experience for students to experience the challenges of functioning on a multidisciplinary team.

All senior design students are required to submit both oral and written reports on their projects throughout the course. The funding provided by the EAFB design clinic gave the faculty advisors on this project the opportunity to enrich the communications portion of this course. Students were required to give oral progress reports on a weekly basis. The reports were critiqued by three faculty. Two of the faculty advisors have extensive industry experience. This exposed students to many of the presentation styles currently used in industry. In addition to the standard report on their project, the student participants were also required to write a paper for submission to a conference.

The assessment of this project was informal. However, even without a formal assessment, evidence was collected to indicate that the projects and the format in which they were offered did improve the ability of our graduates to demonstrate the outcomes listed above. The following indications were noted and will be measured formally in the coming year:

- Faculty advisors observed a noted improvement in presentation skills of the students
- Representatives from industry attending student presentations indicated that students made better presentations than generally expected from new graduates and were impressed with the technical level of their work
- Industry representatives also commented on the excellent teamwork
- As compared to other senior design students, the presentations were notably better
- Student participants indicated their satisfaction with working on the project even though they realized it was more work than other senior projects
- Student enthusiasm for the project was evident from their dedication and hard work
- Faculty advisors noted that the use of SDR enabled the students to complete more complex and interesting projects in the communications area.

One negative aspect of this project was the amount of faculty support that it required was well above the level that is normally available to senior design students. In this case the support was possible due to the funding available from the EAFB Design Clinic and the faculty interest in SDR. The department is investigating ways to implement the model used in a more cost effective manner.

VI. Conclusion

This paper demonstrated that utilizing software defined radio to design and implement a communication system for a UAV can not only work but, in many cases, can surpass traditional hardware based methods. This project spanned a broad spectrum of different disciplines within electrical and computer engineering. Due to the scope of this project and the number of people working on it, this project worked well to develop many of the skills required by industry that are not typically developed in the classroom. The group was expected not only to work together, but to manage time, make timely decisions about which tasks could or could not be accomplished, and to work under deadlines that may be six months to a year out. The group had to develop skills to communicate on the project's progress. All of these skills are useful to industry and this makes this type of project advantageous for graduating seniors as a culminating experience.

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Six by Six Terrain Vehicle for Optimal Mass, Geometric Configuration and Tractive Efficiency

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Abstract

This paper presents a new design methodology for determining the optimal mass, geometric configuration and wheel power distribution of a 6x6 terrain vehicle, in order to provide the vehicle with optimized traction. The educational aspect of this paper is to motivate and integrate student learning process through mathematical models and equations for design.

The methodology is realized using a mathematical model of a 6x6 wheel drive tractor satisfying the off-road profile. The methodology is used to find the optimum co-ordinates for the center of gravity and optimum arrangements of the middle axle wheels along the tractor. The optimal tractive efficiency is then achieved by optimizing the geometric coordinates.

Educational value of the paper

This paper is basically an analysis-based learning approach to motivate and integrate student learning process. This approach will increase student's motivation because it introduces the engineering content early in the curriculum and helps them understand the concepts practically.

This analysis is initially performed as an independent study at a graduate curriculum. A graduate student worked upon this lesson-study allowed him to better understand the concepts like moment of inertia, damping and center of gravity in real-time applications. So, this would definitely be helpful for undergraduate students taking mechanical vibration, dynamics and vehicle design classes. The students could study the location of various components and understand how the selection of spring-stiffness, damping, axle coefficients, and distance between axles could have impact on the performance characteristics of the vehicle. This work would definitely serve as a guideline for students interested in doing vehicle design projects. The work could be used as a reference for the students of the Mini-Baja and Formula-SAE projects in the Mechanical Engineering Department.

This paper delivers a mathematical model with analytical equations that provides a various options for designing acceptable vehicle models. Further research and simulations need to be performed for a detailed study. This approach will give undergraduate and graduate engineering students better scope on designing concepts and they will have more knowledge on the fundamentals. This approach will also allow students to: i) tolerate ambiguity that shows up in viewing design as inquiry or as an iterative loop of divergent-convergent thinking, ii) maintain sight of the big picture by including systems thinking and systems design, iii) handle uncertainty, iv) make decisions, v) think as part of a team in a social process, and vi) think and communicate in the several languages of design.

As far as the educational value of the paper is concerned, the students get to know more about the modeling of a mechanical system. In this study engineering students will come to know how to frame the equations of motion for six wheel drive terrain vehicles and other vehicles with similar characteristics. The equations for various forces acting on the system, stiffness, and moments of inertia could be realized by the students. This approach will give them a practical view of solving a vibration and dynamics oriented problem. Doing so will help them understand better and solve various problems involved in engineering design. The paper will also teach the students how choosing the values for stiffness and framing the equations of motion could affect the stability of the system.

Introduction

Many definitions are given in the automobile literature for the off road multiple wheel drive vehicles [6, 7, 8]. Basically, the performance of off road vehicles is defined as the property that enables a vehicle to move successfully and reliably on varying (macro and micro) road conditions by overcoming various obstacles. A 6 wheel drive off -road vehicle's performance may be improved by controlling individual wheel torques [1]. Individual control of wheel torques such as traction control and anti-lock braking improve vehicle handling and stability in cornering. Multidisciplinary Design Optimisation (MDO) is a very useful technique for solving any multi-body dynamics problem [20]. MDO is a body of methods and techniques for performing the optimization so as to balance the design considerations at the system and detail levels. Another approach to improving vehicle performance is to integrate both the vehicle operational properties and adaptive vehicle dynamics [2, 3, 4]. However, analysis of mass and geometric parameters may provide a basis needed to better understand vehicle performance.

Several parameters which affect the fuel consumption, performance, and top speed of a vehicle are vehicle weight, tire rolling resistance, aerodynamic drag and driveline configuration [28]. Studies have indicated that it is possible to change each of these parameters to reduce the fuel consumption of a vehicle. The basic mass and geometric parameters of all-wheel drive off-road vehicles, such as coordinates of the center of gravity and wheel arrangements, are usually achieved to reduce the dynamic normal loads on the running gear system while satisfying the off road profile [5].

The geometric vehicle characteristics such as front and rear trafficability angles, and the longitudinal and cross radii of trafficability should satisfy the trafficability requirements. However less attention is given for studying the influence of the center of gravity placement and wheel arrangement on traction and velocity properties for basic off road mobility of vehicles. Therefore, off road mobility may be understood as the ability of the vehicle to move outside of roads with or without load [9]. Furthermore, basic off road mobility is a complex vehicle performance that interconnects traction, velocity, and surface grip properties of vehicles. These properties are fundamental to estimating basic on/off road mobility. For tractors, traction and velocity properties together provide adequate drawbar to pull various implements and machinery.

Heavy vehicles with high centers of gravity are prone to rollover accidents. For a given height and width, stability is affected by suspension design. In articulated vehicles, the matching of the tractor and trailer suspensions, as well as the degree of coupling between tractor and trailer, affects the stability of the combination. The effects of suspensions, couplings, tires and chassis on the rollover limit are also to be considered [25]. The traction and velocity properties of vehicles are characterized by their ability to move under an action of the circumferential forces exerted on the drive wheels [5, 6]. These properties are usually examined with fuel consumption. Taking the generalized parameters for traction as the average vehicle speed, V_{mid} and the average fuel consumption, Q_{mid} we may determine the vehicle's productivity, *SP*, as follows [4]:

$$SP = G_l V_{mid} / (g Q_{mid}) \quad (1)$$

where G_i is the weight of the handling load (payload) and g is the gravitational acceleration.

The vehicle's fuel consumption per unit of productivity, SP_o is defined [11] as:

$$SP_0 = 1/SP \quad (2)$$

Understanding the effects of tire and vehicle properties on the rollover propensity of tractor semi-trailer trucks is essential. A simplified computational tool can be used to understand and predict the effects of various tire characteristics and truck design parameters on rollover under steady cornering and non-tripped conditions [29]. The traction and grip properties define the interaction between the drive wheels and a surface on which the tractor moves. These properties are typical in the tractor engineering and provide a measure for the tractor's ability to tow trailers and to work with agricultural machines. The tractor transport efficiency, η_{tr} provides the overall efficiency of a tractor and may be defined as:

$$\eta_{tr} = G_l V_r / N_e , \quad (3)$$

Where N_ε the power is input to the transmission and V_r is the actual forward speed of the vehicle. The transport efficiency is a product of three components [8]: The lift/drag ratio C_{ld} (or the ratio of the total vehicle weight to the total motion resistance), structural efficiency η_{st} (or the ratio of the payload to the vehicle total weight), and propulsive efficiency η_p.

Equations (1) and (3) show the structure of the specific productivity is similar to the efficiency coefficient defined with Wong's transformations [8]. The Rolling resistance is a very important factor to be considered in obtaining increased tractive forces [30]. In estimating the tractive efficiency, and transport efficiency of tractors in basic off road mobility, we will be taking the advantage of the running gear efficiency. General mathematical formulas to account for running gear efficiency as a function of transport and tractive efficiency are provided in [10]. Therefore, in view of these dependencies, we generate a formula to calculate the tractive efficiency of a 6 wheel drive tractor moving on a horizontal soft terrain with a drawbar pull.

In this paper we develop a new design based methodology, subject to optimization of the tractive efficiency constraint function, for determining the optimal mass and geometric parameters that provide a vehicle with the optimized traction and velocity properties for off road mobility. The method uses a mathematical model of a six-wheel-drive tractor on soft terrain. The underlying idea is that the optimal parameters provide the tractor with optimized tractive efficiency on its running gear system.

Methodology: One sixth tractor model

A common representation of the interaction between a vehicle system and the road surface in the vertical direction is the two degree-of-freedom system shown in Fig.1.

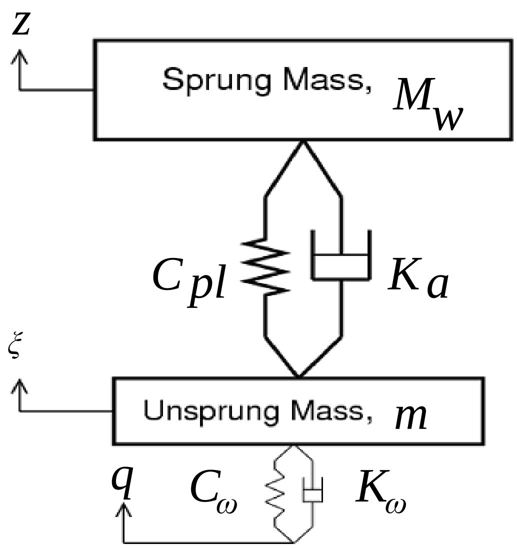


Fig. 1. One - sixth tractor model

This basic model is used in a number of different circumstances to describe the behavior of a vehicle suspension system. Mathematically, the relationships embodied in the model are given in Eq. (4).

$$M_w \cdot \ddot{z} = C_{pl}(\xi - z) + K_a(\dot{\xi} - \dot{z})$$
$$m \cdot \ddot{\xi} = C_{\varpi}(q - \xi) + K_{\varpi}(\dot{q} - \dot{\xi}) - C_{pl}(\xi - z)$$
$$-K_a(\dot{\xi} - \dot{z}) \qquad (4)$$

Where M_w is the one sixth tractor model effective sprung mass. This “one-sixth tractor” model can be implemented readily in a variety of simulation packages such as Matlab Simulink. Road input that matches the natural frequencies of the vehicle will cause suspension deflection which exceeds the magnitude of the input. The one-sixth tractor model is characterized by two natural frequencies, one for each mass in the system. The natural frequencies of the sprung and unsprung masses can be approximated with Eq. (5) and Eq. (6).

$$f_{n-sprung} = \frac{1}{2\pi}\sqrt{\frac{C_{pl}C_{\varpi}/(C_{pl}+C_{\varpi})}{M_w}} \qquad (5)$$

$$f_{n-unsprung} = \frac{1}{2\pi}\sqrt{\frac{C_{pl}+C_{\varpi}}{m}} \qquad (6)$$

The one-sixth tractor model provides a stepping stone to a more complex model incorporating vehicle pitch and roll. A representation of a six wheel drive full tractor model derived for multi axles is shown in Fig. 2.

Full tractor model

A schematic of the tractor is shown in Fig.2. The tractive efficiency of the tractor in a running gear can be determined as follows:

$$\eta_x^t = N_{xp}/N_x, \quad (7)$$

where N_{xp} is the drawbar power corresponding to the drawbar pull (F_d), and N_x is the power delivered to the drive wheels. Powers N_{xp} and N_x are equal to, respectively,

$$N_{xp} = F_d V_r \quad (8a)$$

$$N_x = \sum_{i=1}^{3} F_{xi} V_{ti} = V_r \sum_{i=1}^{3} F_{xi} /(1 - s_{\delta ai}) \quad (8b)$$

where V_{ti} is the theoretical wheel speed of an axle with index i (i=1,3), F_{xi} is the tractive force of the i^{th} wheel and $S_{\delta ai}$ is the wheel slip coefficient of the i^{th} axle. Thus, the tractive efficiency is determined as follows:

$$\eta_x^t = F_d /(\sum_{i=1}^{3} F_{xi} /(1 - s_{\delta ai})) \quad (9)$$

To calculate the tractive efficiency, we need a function between the tractive force, F_{xi} and the wheel slip coefficient $S_{\delta ai}$. For this purpose, we use the most common function:

$$F_{xi} = R_{zi} \mu_{pxi} (1 - exp(-k_{moi} s_{\delta ai})), \quad (10)$$

where R_{zi} is the i^{th} wheel normal reaction, the factor K_{moi} and the cohesion (grip) coefficient μ_{pxi} are both dependent on properties of the tire and ground contact. The approximate values for μ_{pxi} and K_{moi} are usually determined using experiment data. In addition, these values may be different for the wheels of the three axles moving in the same track on a soft surface.

It is necessary to emphasize here that the placement of center of gravity and axle arrangement along the tractor base may influence the normal axle loads and subsequently tractive forces and tractive efficiency of the tractor's running gears. Thus, by determining the normal load as dependent on coordinates of the gravity center and placement of the middle wheels, it is possible to find a combination of these coordinates appropriate for maximum tractive efficiency. The geometric tractor parameters found in this way provide not only the most feasible engineering solution but also the most economical tractor for basic off road mobility. In order to achieve these parameter values, we make a mathematical model of the tractor with an individual wheel suspension as shown in Fig.1. To determine the axle normal reaction values, we use force and moment balance equations acting on the tractor as follows:

$$R_{z1} + R_{z2} + R_{z3} - R_{z4} = W_a, \quad (11)$$

taking the moments about point O_1 of Fig.1:

$$W_a l_a - \sum_{i=1}^{3}(F_{xi} - R_{xi})a_i + F_d h_d - \sum_{i=2}^{3} R_{zi} l_i + R_{z4} l_4 = 0 \quad (12)$$

where W_a is the weight of the tractor and R_{z4} is the vertical downward trailer hitch force. The displacements, a_i's (i= 1, 3), are usually found from tire-ground interaction.

It is clear from above that the number of unknown axle normal reactions exceeds the number of equations (11) and (12). To solve this problem, we take advantage of the equations of elastic travel, Z_i of the tractor frame points above the three axles having three individual suspensions. These equations are as follows.

$$R_{zi} = C_{ri} Z_i \quad (13)$$

$$C_{ri} = \frac{C_{si} C_{ti} C_{gi}}{C_{gi} C_{si} + C_{ti} C_{gi} + C_{si} C_{ti}}, \; i = 1, 3, \quad (14)$$

Where C_{ti}, C_{gi}, C_{si} are the tire, ground, and suspension stiffness, respectively. The C_{ri} is called reduced rigidity stiffness of the suspension - tire - terrain system. To transform the travel of the points above the second and third axles; through the travel of the point above the first axle, the longitudinal axle coordinates and the inclination angle, θ of the frame relative to the surface of motion, we obtain the following formulas for the axle normal reactions:

$$Z_i = Z_1 - l_i \tan\theta, \; i = 2, 3, \quad (15)$$

Where l_i's is given in Fig.2. Combining equations (12), (14) and (15), and solving for Z_1, we get:

$$Z_1 = (W_{a+} \tan\theta \sum_{i=1}^{3} C_{ri} l_i)/\sum_{i=1}^{3} C_{ri} \quad (16)$$

Solving Eq.(16) for $\tan\theta$ and substituting into Eq. (15), we get the axle normal reactions R_{zi} from Eq.(13):

$$R_{zi} = C_{ri}(((W_a(C_{r2}l_2^2 + C_{r3}l_3^2 - l_a \sum_{i=1}^{3} C_{ri} l_i) + \sum_{i=1}^{3} C_{ri} l_i \sum_{i=1}^{3}(F_{xi} - R_{xi})a_1 - \sum_{i=1}^{3} C_{ri} l_i F_d (h_d - a_1))/$$

$$(\sum_{i=1}^{3} C_{ri}(C_{r2}l_2^2 + C_{r3}l_3^2) - \sum_{i=1}^{3} C_{ri} l_i (C_{r2} l_2 + C_{r3} l_3)) - l_i((Z_i \sum_{i=1}^{3} C_{ri} - W_a)/\sum_{i=1}^{3} C_{ri} l_i)) \quad (17)$$

where i =1, 2 and 3 with l_1 = 0;

Using Eq. (10) along with equation (17), we can find the tractive forces, F_{xi}'s. Therefore, the equation of motion of the tractor at a constant speed may be written as follows:

$$F_{x\Sigma} = \sum_{i=1}^{3} F_{xi} = \sum_{i=1}^{3} F_{fi}^{0} + F_d + \sum_{j=1}^{s} F_j \quad (18)$$

where $\sum_{j=1}^{3} F_{fi}^{0}$ is the sum of the rolling resistance forces, $\sum_{j=1}^{s} F_j$ is the algebraic sum of external forces acting on the tractor; including air resistance force and the inertial forces. Other forces may be defined by a research problem of interest. In our case of steady motion of the tractor: $\sum_{j=1}^{s} F_j$ =0.

The total rolling resistance forces of axles may be computed by using formulas available. On changing terrain, the front wheels move on non-tamped terrain, the middle wheels move in the track of the front wheels and the rear wheels move in the track of the middle wheels. After calculating the total tractive force, $F_{x\Sigma}$, we may optimize all the tractive axle forces F_{xi}'s, to obtain the maximum tractive efficiency. In this paper I have solved this problem for various combinations of wheel arrangements, different placements of the center of gravity, and for various values of F_d subject to the constraints:

$$\eta_x^t \to max, \tag{19}$$

$$0 < F_{xi}^* < R_{zi}\mu_{pxi}, \; i = 1, 3, \tag{20}$$

$$F_{x\Sigma} = \sum_{i=1}^{3} F_{xi}^* \tag{21}$$

The above analysis provides a mathematical model for the optimization of the basic geometric parameters of a six wheel drive tractor having maximum running gear efficiency. The model was developed with the assumption that the tractor's drawbar pull is horizontal with R_{z4} equals to zero. Figure 2 shows the free body diagram of a six wheel drive independent suspension tractor model on a deformable soil.

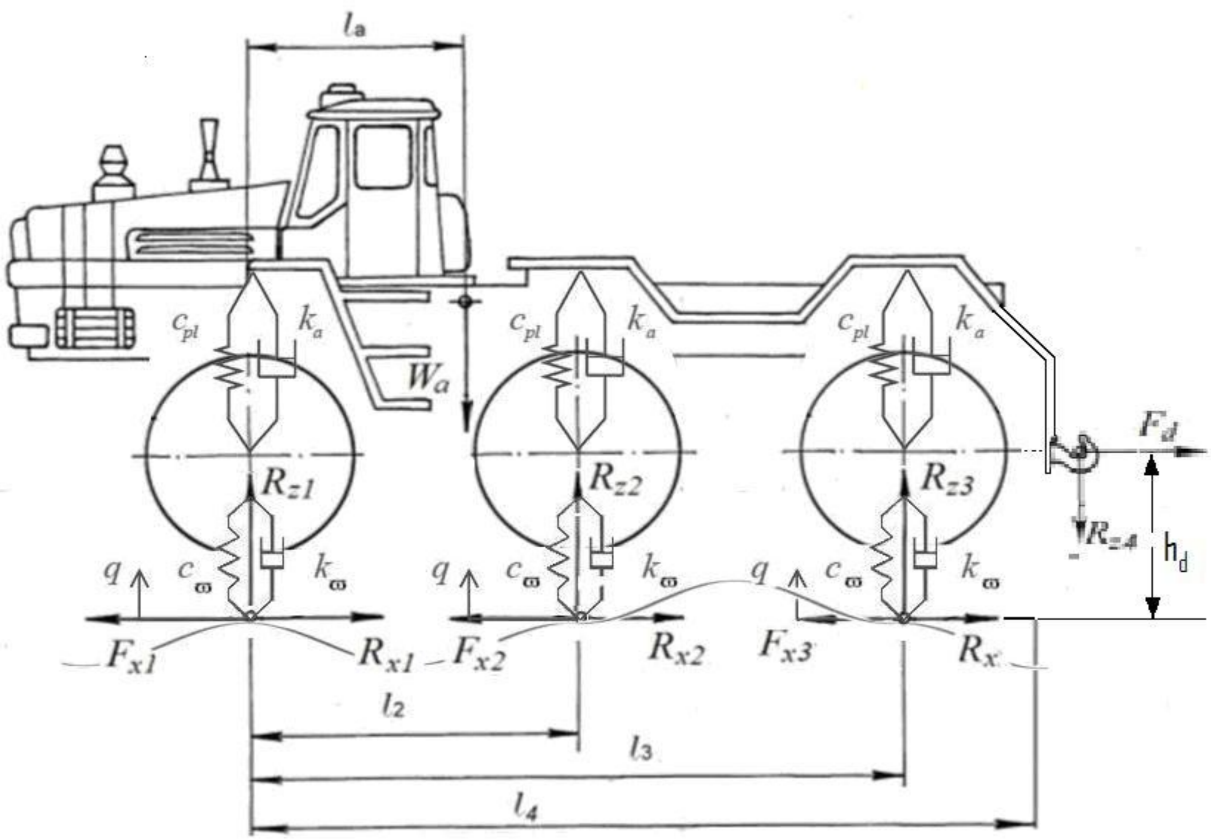


Fig.2. A six wheel drive tractor: free-body diagram

Table.1 Parameters for normal reaction calculation

Parameters/Units	Notation	Value
Weight, kN	W_a	90
Front axle tire normal stiffness, N/m	C_{t1}	840,000
Middle axle tire normal stiffness, N/m	C_{t2}	613,200
Rear axle tire normal stiffness, N/m	C_{t3}	562,800
Suspension stiffness, N/m	$C_{t1} = C_{t2} = C_{t3}$	1,600,000
Soil stiffness under the front axle, N/m	C_{g1}	800,000
Soil stiffness under the middle axle, N/m	C_{g2}	1,800,000
Soil stiffness under the rear axle, N/m	C_{g3}	3,680,000
Front axle rolling resistance coefficient	f_1	0.1
Middle axle rolling resistance coefficient	f_2	0.08

Rear axle rolling resistance coefficient	f_3	0.065
Height of the draw-bar pull from ground, m	h_d	3.5
Radius of the wheels, m	$a_1 = a_2 = a_3$	0.3

The mathematical model of optimization of the distribution of power between the axles for these travel conditions can be rewritten as:

$$\eta_x^t = \frac{F_d}{\sum_{i=1}^{3} F_{xi} + \sum_{i=1}^{3} \frac{F_{xi} s_{\delta ai}}{1 - s_{\delta ai}}} \quad (22a)$$

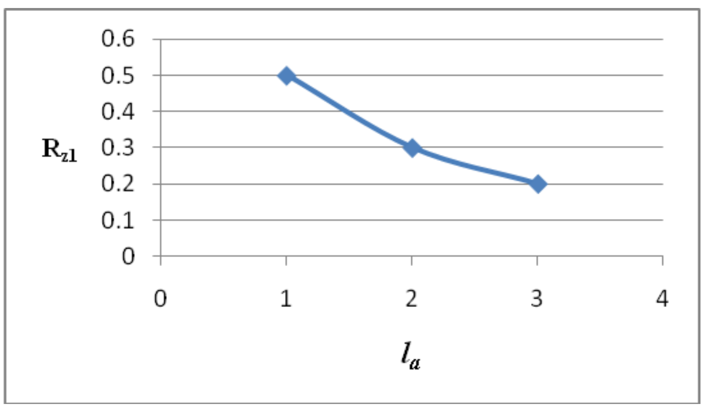
$$\sum_{i=1}^{3} F_{xi} = F_{x\Sigma} = \sum_{i=1}^{3} R_{xi} + F_d \quad (22b)$$

$$0 < F_{xi}^{*} < \mu_{pxi} R_{zi} \quad (22c)$$

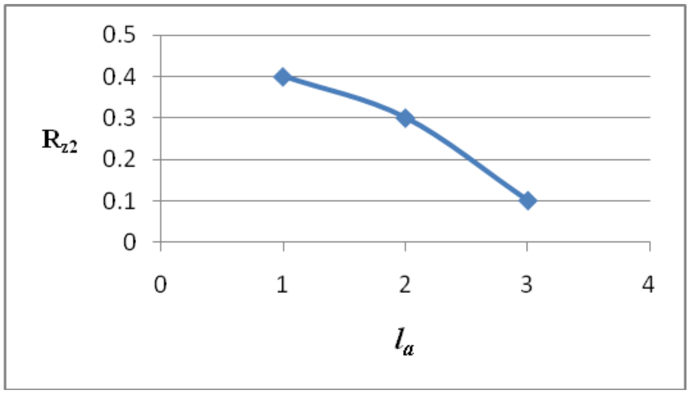
$$F_{xi}^{*} = R_{zi} \mu_{pxi} \left(1 - exp\left(-k_i s_{\delta ai}^{*}\right)\right) \quad (22d)$$

Results

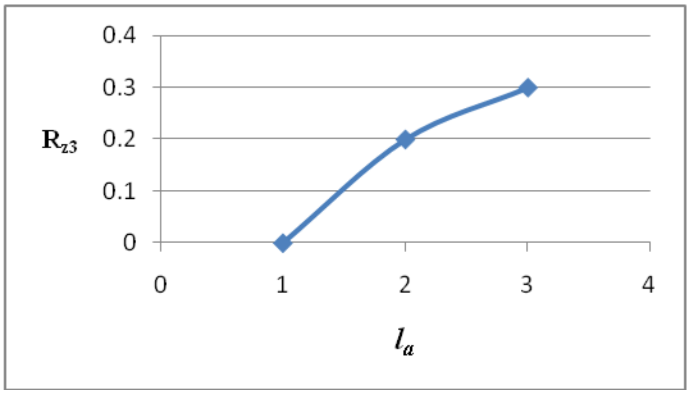
The results of a 9-ton 6×6 tractor with 16.9R30 tires moving over a plowed field with caked soil are as follows. Figure 3 shows the distribution of normal reactions between the axles as a function of the location of center of gravity l_a and for three forms of middle wheel arrangements as close as possible to : i) the front wheels, ii) the middle of the wheelbase, and iii) the rear wheels.



R_{z1} Versus l_a for l_2 =1.5



R_{z2} Versus l_a for l_2 =1.5

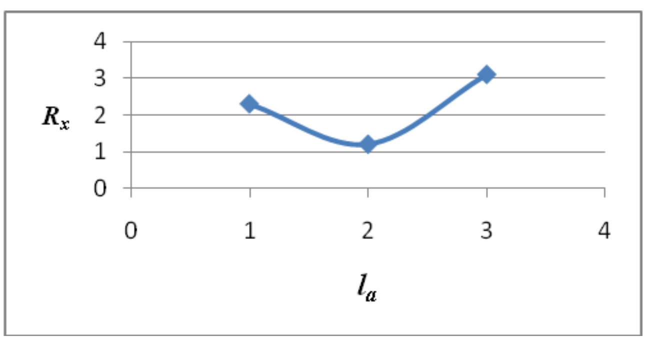


R_{z3} Versus l_a for l_2 =1.5

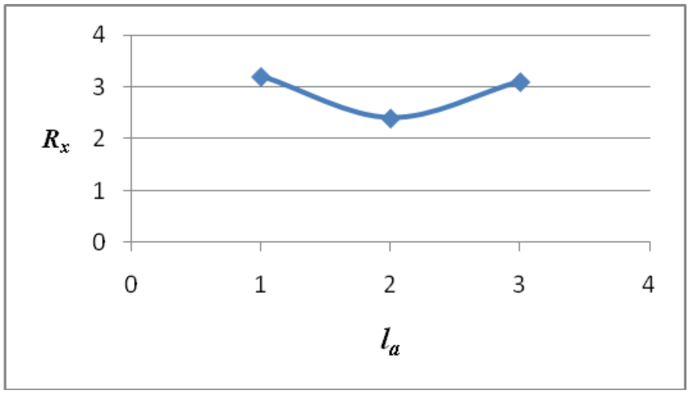
Fig3. Normal reactions of the axles when l_2=1.5

R_x Plots

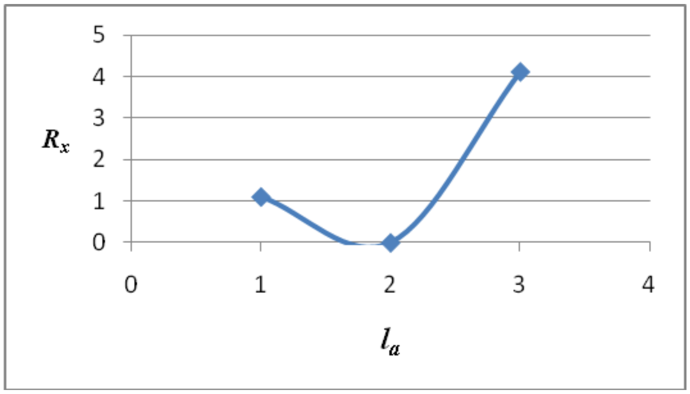
The total rolling resistance curves of the total resistance to the rolling of the wheels, $R_{x\Sigma} = \sum_{i=1}^{3} R_{xi}$, for these three arrangements are plotted in Fig. 4.



R_x versus l_a for l_2=1.5



R_x versus l_a for l_2=2

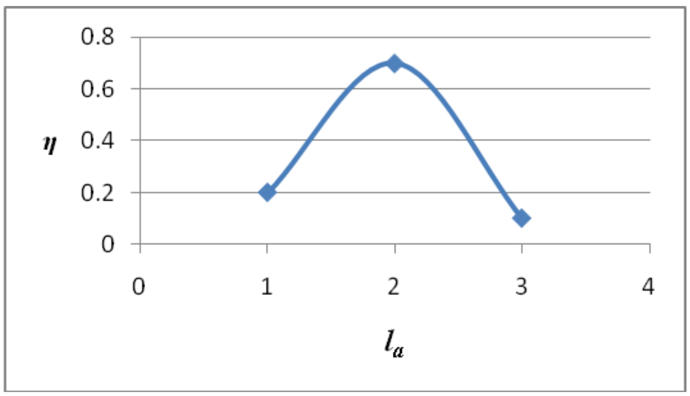


R_x versus l_a for l_2=3

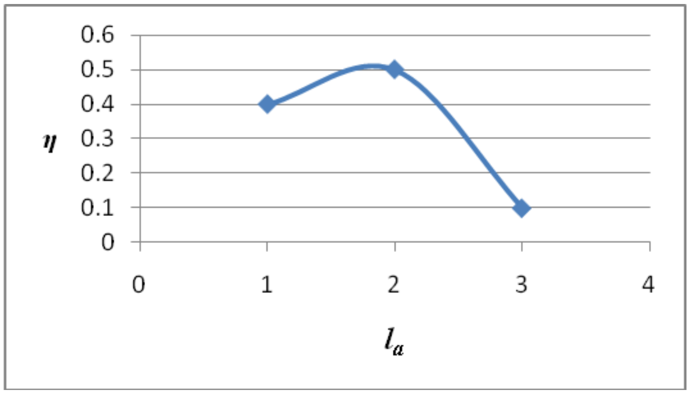
Fig4. Total rolling resistance $R_{x\Sigma}$ for l_2=1.5, 2, and 3.

Efficiency without acceleration

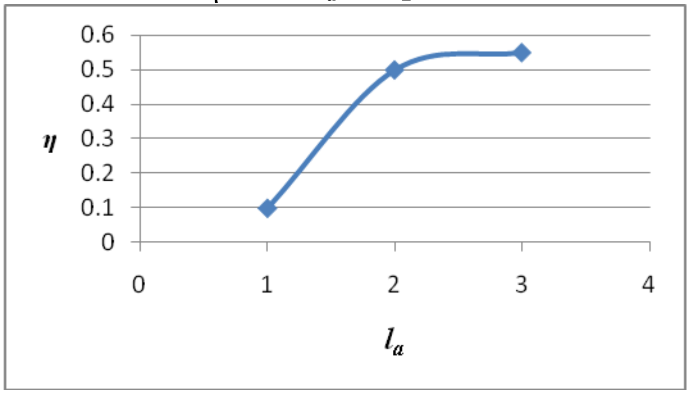
The maximum possible tractive efficiencies on a running gear are shown in Fig.5 provided by the pertinent distribution of power between the axles, where the l_a is along the x-axis and the η is along y-axis.



η versus l_a for l_2=1.5



η versus l_a for l_2=2



η versus l_a for l_2=3

Fig.5. Maximum tractive efficiency of the tractor on a running gear for l_2=1.5, 2, and 3.

The distribution of the normal loads between the axles has a remarkable effect on the rolling resistance $R_{x\Sigma}$. In all the wheel arrangements the value of $R_{x\Sigma}$ is at minimum in regions with uniform distribution of normal reaction R_{zi}. The minimum values of $R_{x\Sigma}$ are observed with increasing F_d at lower values of l_a.

It follows from Fig. 5 that the middle-wheel location arrangements discussed here have, under different traction loads, such locations of the center of gravity l_a at which η_x attains the maximum value of the maximum possible. When F_d increases, the values of l_a decrease for all the three arrangements of the middle wheels.

The maximum possible values of η_x correspond to the minimum of rolling resistance and uniform distribution of the loads between the axles, respectively as shown Figs. 4 and 3. When the middle wheels are shifted from the front wheels to the rear wheels, the maximum efficiency of the maximum possible changes somewhat as depicted in Fig. 5. It is hence of interest to investigate in more detail the effect of parameter l_2 on the traction performance of the vehicle.

Determination of the reaction forces including acceleration

The addition of the acceleration force to the momentum equation shows us a clearer picture of the behavior of the reaction force and also the efficiency. By D'Alembert's Principle we have,

$$F - ma = 0 \tag{23}$$

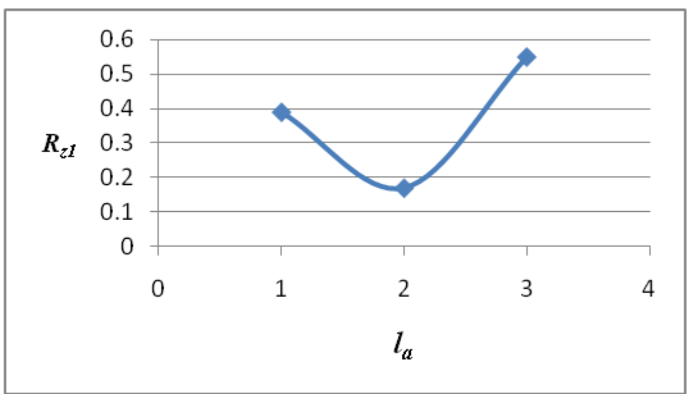
Where 'a' is the acceleration of the vehicle. Now, by adding the acceleration term to momentum equation, Eqn (12) is revised as,

$$W_a l_a - \sum_{i=1}^{3}(F_{xi} - R_{xi})a_1 + F_d(h_d - a_1) - R_{z2}l_2 - R_{z3}l_3 + (W_a / g)a = 0 \tag{24}$$

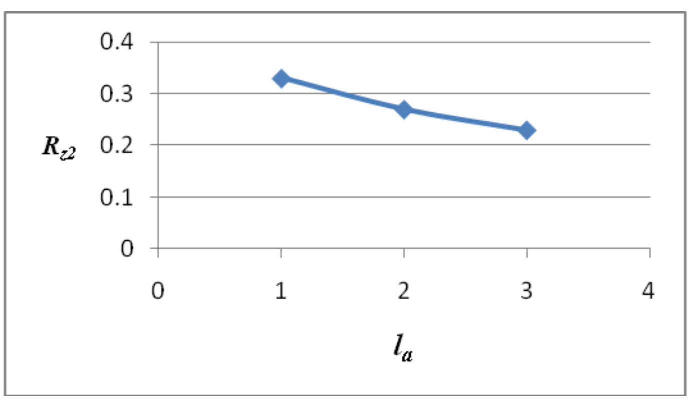
Solving for R_{zi}, we have

$$\text{Rzi} = C_{ri}(((W_a(C_{r2}l_2^2 + C_{r3}l_3^2 - l_a\sum_{i=1}^{3}C_{ri}l_i - (a/g)\sum_{i=1}^{3}C_{ri}l_i) + \sum_{i=1}^{3}C_{ri}l_i\sum_{i=1}^{3}(F_{xi} - R_{xi})a_1 - \sum_{i=1}^{3}C_{ri}l_iF_d(h_d - a_1))/(\sum_{i=1}^{3}C_{ri}(C_{r2}l_2^2 + C_{r3}l_3^2) - \sum_{i=1}^{3}C_{ri}l_i(C_{r2}l_2 + C_{r3}l_3)) - l_i((Z_i\sum_{i=1}^{3}C_{ri} - W_a)/\sum_{i=1}^{3}C_{ri}l_i)) \tag{25}$$

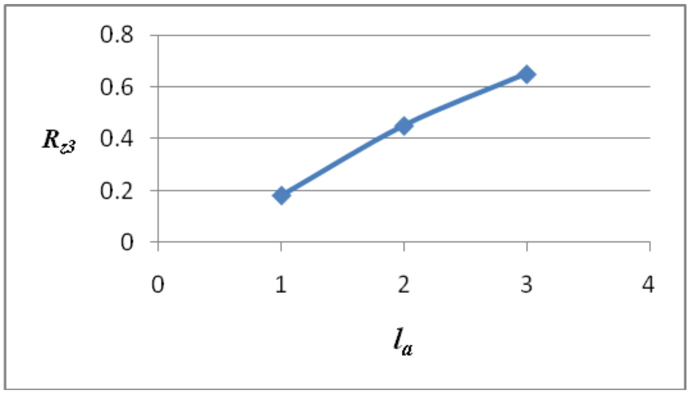
Results



R_{z1} versus l_a for l_2=1.5



R_{z2} versus l_a for l_2=1.5

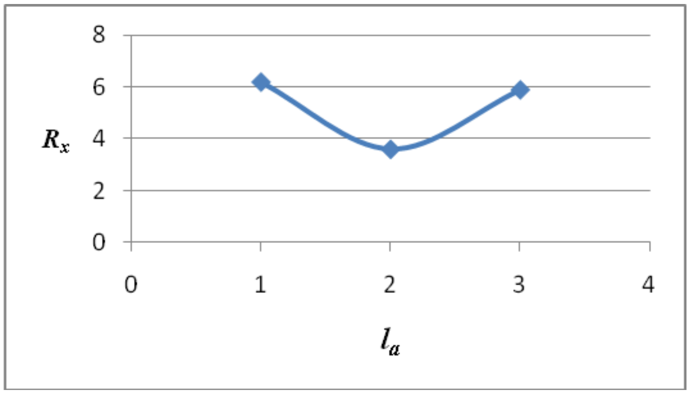


R_{z3} versus l_a for l_2= 1.5

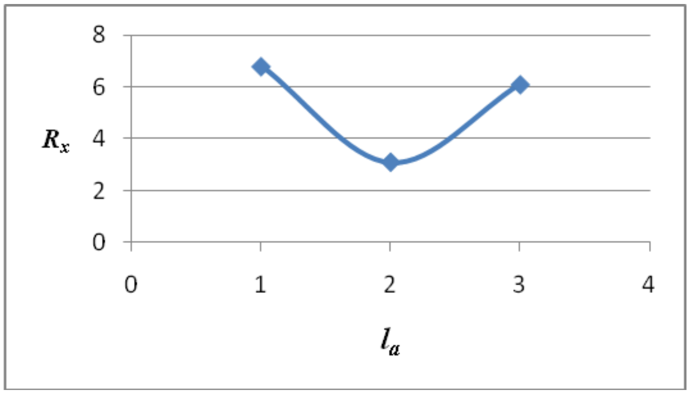
Fig6. Normal reactions of the axles when l_2=1.5

R_x Plots

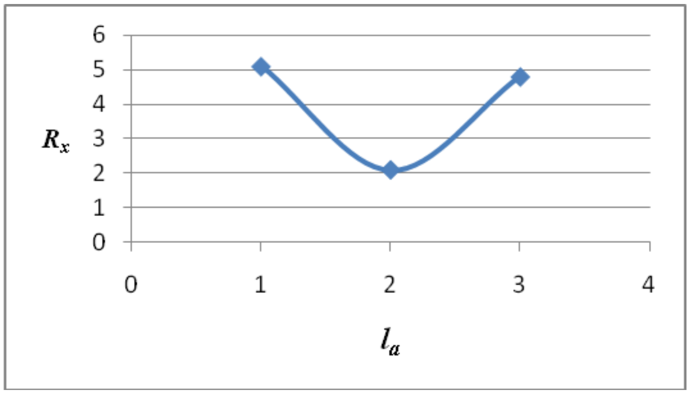
The total rolling resistance curves of the total resistance to the rolling of the wheels, $R_{x\Sigma} = \sum_{i=1}^{3} R_{xi}$, for these three arrangements are plotted in Fig.7.



R_x versus l_a for l_2=1.5



R_x versus l_a for l_2=2

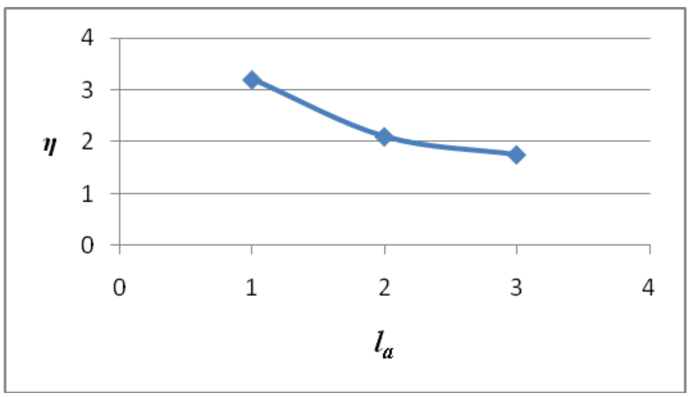


R_x versus l_a for l_2=3

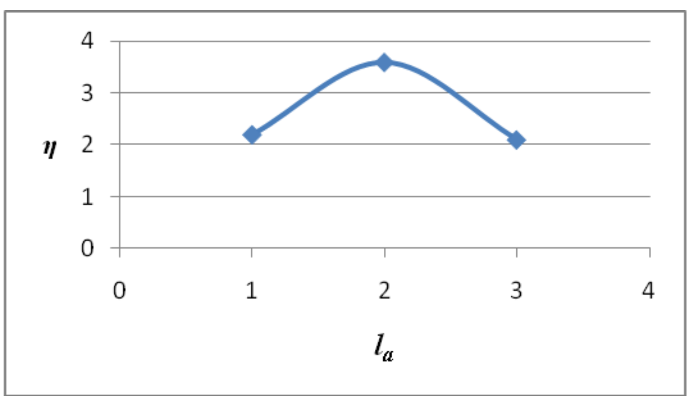
Fig7. Total rolling resistance $R_{x\Sigma}$ for l_2=1.5, 2, and 3.

Efficiency with acceleration

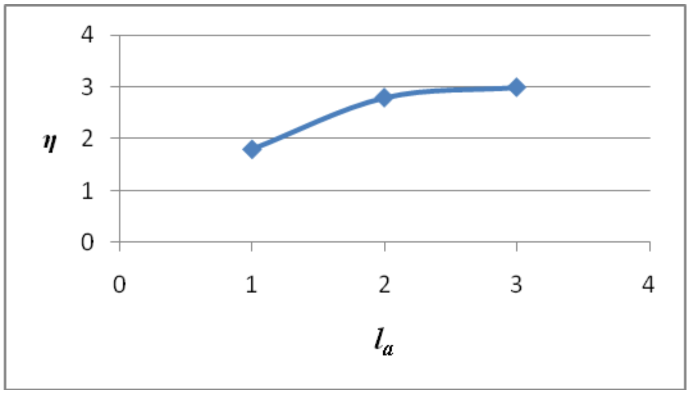
The maximum possible tractive efficiencies on a running gear are shown in Fig.8 provided by the pertinent distribution of power between the axles where η is along y-axis and l_a is along x-axis.



η versus l_a for l_2=1.5



η versus l_a for l_2=2



η versus l_a for l_2=3

Fig.8. Maximum tractive efficiency of the tractor on a running gear for l_2=1.5, 2, and 3.

Conclusion

The results show the influence of the driveline system parameter arrangement of a six wheel drive tractor on rolling resistance forces, power needed to overcome these forces, and power lost due to drive wheel slippage all of which determine the efficiency of the running gear system. The developed theoretical statements and mathematical model have been used to solve the following problems: a) determination of optimum coordinates of the center of gravity under the given arrangement of the middle axle wheels along the tractor base; b) determination of optimum arrangement of the middle axle wheels along the base under the given coordinates of the center of gravity; c) determination of optimum coordinates of the center of gravity and arrangement of the middle axle wheels along the tractor base. We were also able to see how the consideration of acceleration influenced the various plots. The curves got shifted indicating the increase in the tractive force of the vehicle. Similarly, we could generate the plots for different values of l_2 for maximum traction.

Recently, various devices have been developed to replace the vehicle's center of gravity position for changing drawbar pull. The paper can be further extended by also considering other dynamical factors acting on the vehicle. The result of this paper can be used for the development of optimum algorithms to control the replacing process.

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Work in Progress: A Student Developed Repository of Design Knowledge

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Introduction

The construction and use of a repository for design knowledge can serve several roles in an educational setting. For the instructor, the repository can act as a window into the students' design process, status in a design project, and understanding of design concepts where the construction and use of elements of design knowledge require achievement at levels of learner knowledge corresponding to basic understanding, understanding of relationships, and transfer of knowledge. For the student, the repository can be a source of solutions to specific design problems and provides the structure and easy to use digital tools for reporting on design accomplishments. This presentation reviews the implementation of a design repository used in a sophomore mechanical engineering design course.

Design Knowledge Repositories

In practice, organizations manage knowledge in order to leverage the varying expertise of employees separated by location, cultural barriers, or time. In the context of engineering design practice, this knowledge can be can be used to spark conceptual design innovation or shorten product development in various ways by enabling the reuse of proven methods and artifacts.

The operations that must be addressed in order to realize a design repository are 1) a representation for a design knowledge element, 2) a method for storing or uploading the knowledge, and 3) a method of searching and retrieving the knowledge for reuse. Several implemented repositories provided the background for the structure of the design knowledge repository. Szykman and Sriram[1] developed a design repository software system that provided insights into the use of design repositories in conceptual design. Bohm et al.[2] developed a data representation for use in design repositories that captures multiple attributes of components or assemblies including core elements of form and function. Hart et al.[3] proposed a framework and use of cyber infrastructure to guide design learning through dissection activities.

Implementation

In previous applications, design repositories have been put in place to "allow designers to store and retrieve design knowledge at various levels of abstraction — from form…to function."[2] In order for students to successfully use a design repository they must achieve at multiple levels of learner knowledge[4] to understand the core concepts that define an element of reusable knowledge (information level), understand how a design concept can be decomposed into elements of design knowledge and are related to elements of design knowledge from other students (understanding level), and be able to transfer the design knowledge to a new design problem (application level).

In this design repository, students used digital pens and a wiki to document a product level representation of their design and a component level representation of several elements of their design. The product level representation constituted a wiki page that contained a sketch of the entire product, acquired using the digital pen, and a decomposition of the product into a table of components and corresponding functions. The students also completed several component pages, each of which defined an element of design knowledge that can be reused. The component pages were linked from the product decomposition table.

The design knowledge representation (component page) consisted of three basic elements 1) the form of the component, assembly, or sub-assembly, 2) the function of the component, assembly, or sub-assembly, and 3) a math model, including all assumptions and equations used for analysis and design decision making. In order for students to construct and reuse elements of design knowledge they must first understand the concepts of function and form and the governing math and science related to the components. Their understanding of these basic elements is revealed through an evaluation of the correctness of each element alone and with respect to other elements on the page (i.e. the component was labeled with an appropriate function).

The wiki tagging structure was used to apply function tags to each of the design knowledge elements. The tagging process provides insights for the instructor into student ability to connect concepts of function in their product to abstract concepts of function that generalize across all electro-mechanical devices. The tagging also serves as the mechanism for locating design elements for reuse. The wiki structure provides a tag cloud through which future students can search the component pages (physical form and math model) for options that address their functional needs.

The use of structured forms to evaluate student design work at intermediate and final stages of design has been piloted in other forms[5] with positive results. In courses with large student to instructor ratios, a design repository provides the opportunity to evaluate and provide feedback on student work in a timely and concise manner while still providing insights into their depth of knowledge in design in general and in the context of their projects.

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Three Stage Vibration Isolation For Unmanned Aerial Vehicle Gimbal Targeting System

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Abstract

A student project funded by the air force, required mounting a high resolution camera, TASE gimbal, to be mounted in a model airplane powered by a gasoline engine. Model airplanes such as the Sig Rascal experience vibration and excitation forces derived from the rotating blades and the reciprocating parts of the gas engine. These forces are transmitted through the engine mounts to the fuselage and other parts of the airplane. The transmitted vibrations to the fuselage of the Sig Rascal caused TASE gimbal and the electronics mounted in the fuselage of the Sig Rascal to fail in operation. In order for the mounted equipment to work properly, the vibrations had to be reduced to acceptable levels. The vibration studies were conducted to determine the loads exerted to the fuselage by the rotating blades and the gas engine. Vibration loads of 18g were recorded in the Sig Rascal TASE gimbal mount. Therefore, a major objective was to reduce the forces transmitted to the TASE gimbal mount. To resolve this, shock and vibration absorbing studies were conducted and proper materials were introduced to isolate vibrations from important components such as the TASE gimbal. The design of vibration isolators consisted of three stages. The first stage isolates the vibrations to the engine mount from the blades and the gas engine. The second stage isolates vibrations from the engine mount to the fuselage of the airplane. The third stage isolates vibrations from the fuselage to the gimbal mount. The third stage incorporates Broad Temperature Range Elastomers (BTR) mounts, which were found to be of the optimum material given the base vibrations experienced by the TASE gimbal mounts. The vibration measurements show that the vibration loads to TASE gimbal were reduced to less than 3g's in all the X, Y, and Z axis with vibration absorbing materials. A performance comparison of the vibration isolation system between a gas and an electric engine was also studied. A graduate and an undergraduate student performed the experimentation and data gathering, and with the aid of their instructor, analyzed the nature of the vibration. An effective solution was implemented that allowed the TASE gimbal to function satisfactorily and the airplane to achieve mission goals.

1. Introduction

Laser targeting systems implemented on Unmanned Aerial Vehicles (UAV) such as the TASE gimbal depends on the accuracy of instruments such as accelerometers, gyroscopes, pressure sensors, and Global Positioning System (GPS) to determine accurately the position and distance to target. These instruments almost always required vibration isolation. When measuring and determining position to target, a highly stable surface must be maintained upon which to mount the targeting system. Any vibrations coupled into the mechanical structure of the TASE gimbal will result in displacement and position noise and ultimately in the inability of the instrument to accurately determine the position of the target. Therefore, it is essential to design and implement a vibrations isolation system that will allow for proper operation of such instruments.

The Unmanned Aerial Vehicle Laser Targeting System founded by Edwards Air Force Base enticed a team of interdisciplinary mechanical, computer and electrical engineering faculty and students at CSU, Fresno. The main objective in this project was to enhance electrical, computer and mechanical engineering students' technical as well as soft skills through a comprehensive teamwork experience. Under the supervision of four professors from electrical, computer and mechanical engineering, an interdisciplinary team of over 15 students engaged in the design and testing of an Unmanned Aerial Vehicle (UAV).

In a team environment, the students had a team leader with task specific members who performed the specified tasks and reported to the team leader and the supervising professors in weekly meetings. Students proved successful in coordinating their efforts and solving challenging technical problems. The technical focus was on establishing a communication link with the plane while observing its flying conditions via a proper set of sensors like accelerometers, gyros, GPS, temperature, and cameras. While flying at a range of altitudes from 100 - 400 feet with a path radius less than half a mile, a stationary target was marked using a laser beam while observing it via a camera link. This required addressing payload and vibration problems and developing a real-time feedback pointing system for marking the target. Students also considered alternative solutions including electric versus gas engines to circumvent problems related to vibrations.

This project enhanced students' technical skills in addressing problems related to system specifications and integration, identifying the proper components needed for a specific system performance, and realizing the need for interdisciplinary knowledge through team work. Additionally, the students matured in their leadership, oral and written communication, and critical thinking skills.

2. Design of Vibration Isolation Systems

The design process focused in adjusting the physical parameters of the vibration isolation systems to cause the device vibration response to meet the desired performance criteria. Available products were used to produce the desired vibration isolation configuration for the TASE gimbal. Design considerations concentrated in the weight, shape and size of the TASE gimbal. The vibration disturbance generated by the engine pistons and the heat released by the engine were considered during the design processes. Temperature in particular played an important part in the material selection process for the vibration isolation components, since the elastomers mechanical properties can be altered by the change in temperature [1]. Another important parameter considered was the acceptable level of vibration. For the TASE gimbal, the allowable max vibration response for proper operation was 3g's.

The vibrations experience by the TASE gimbal derived mainly from the reciprocation motion of the gas engine and the rotating propeller. The reciprocating motion of the pistons in the gas engine creates an abrupt disturbance, resulting in vibration transmitted to the gimbal [2]. Rotating unbalance do to small irregularities in the distribution of mass in the propeller also contributed to the increase in vibrations [3].

The design of the isolation systems implemented isolates both, the gas engine from the Sig Rascal, and the TASE gimbal from the fuselage. Sorbothane or ultra-soft polyurethane was the material selected to reduce the vibration displacement transmitted from the gas engine to the fuselage and the force transmitted from the engine through its mounting points to the fuselage. Sorbothane was selected because it has excellent dampening properties, absorbs vibration and it is high temperature resistance. In addition, Sorbothane is durable and resilient enough to return to its original shape after repetitive compressions [4].

Vibration absorbers were used in the design of the vibration isolation system. This consisted in the addition of a second vibration isolation stage added to the primary vibration isolation system. The major outcome of adding the second isolation system is to change from a single degree of freedom to a two-degree of freedom system. This new system now has two natural frequencies; the added system is namely called or referred to as the absorber [5]. This principle is used in the isolation system for the SAITO 180 gas engine. In this case, the primary isolation system consists of the engine mounts, and the absorber consists of the vibration isolation system from the SAITO 180 engine to the engine mount. In addition, damping was also added to the vibration absorber to prevent resonance and to improve the effective RPM operation of the vibration absorber. The damping material used in this case was sorbothane which helped by dissipating the vibration of the gas engine reciprocating motion. Figure 6(b) illustrates the vibration absorber attached to the engine mount.

Viscoelastic damping treatments were also commonly used in the vibration isolation system to effectively reduce vibrations. This was achieved by increasing the amount of damping in the vibration isolation system, so that the energy was dissipated more efficiently [6]. This method was particularly useful in this application because the addition of mass and space required for absorber systems is not practical. The damping treatment consisted of layers of ultra-soft polyurethane, latex, santoprene and copper plates to form a structure that has both stiffness for static loading and damping to reduce the vibrations. The concept of critical speed was also taken into consideration. All vibrations isolation components were design to operate between 2000 rpm to 8000 rpm of the Sig Rascal gas engine. Figure 1 illustrates a damping treatment as installed to the engine mount.

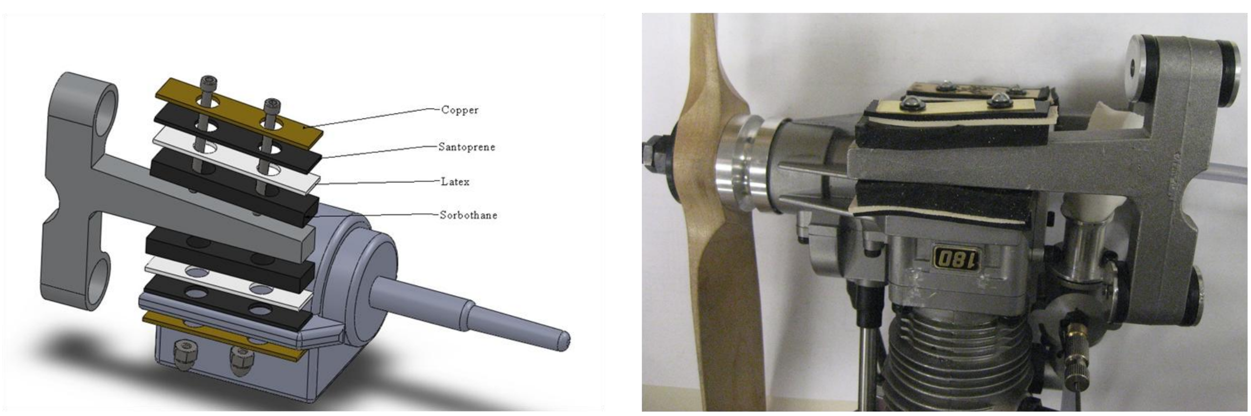
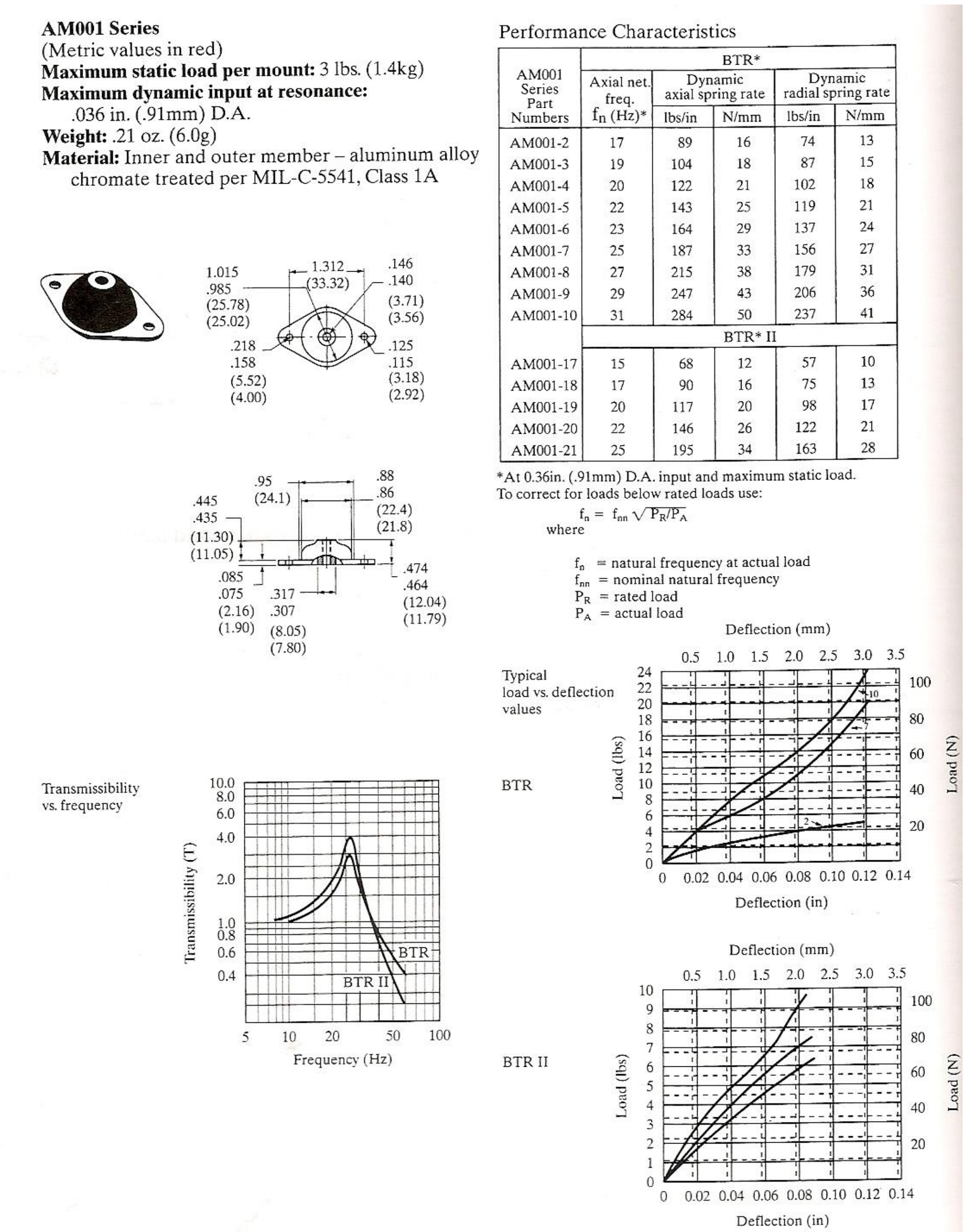


Figure 1. Viscoelastic damping treatment

The third stage vibration isolation system incorporates Broad Temperature Range (BTR) elastomer mounts (Figure 9), which were found to be of the optimum material given the base vibrations experienced by the gimbal mount. These special mounts separated the TASE gimbal mount from the Sig Rascal fuselage. Four BTR elastomer mounts were used to support the bottom of the TASE gimbal mount, plus two additional soft dampers in the horizontal support beam of the TASE gimbal mount (Figure 10).

In the design process for the mounting of the TASE gimbal mount, special consideration was given to the clearance between the Sig Rascal fuselage and the gimbal mount. This clearance is important since any contact point between the fuselage and the gimbal would result in force transmitted to the TASE gimbal. For this design, it was measured that the Sig Rascal was at room temperature operating at 40 Hz (at 2400 rpm the gas engine started producing significant vibration induced force that was transmitted to the fuselage) and that its engine had a mass of 1 kg (2.2 lbs). Figure 2 is used to determine an appropriate isolator so that the transmissibility (T.R) is less than 1. Given that the frequency f = 40 Hz, mass m = 1 kg (2.2 lbs) and T.R<1. The maximum static load per mount is 3 lbs; therefore, the system would require a minimum of 2 mounts. Assuming that four mounts are used; thus, $\frac{2.2\ lbs}{4}$=0.55 lbs per mount. For the isolator, the natural frequency $f_n < 0.5$ and f = 0.5(40) = 20 Hz. Referring to the performance characteristic of the table in Figure 2 yields 4 possible isolator choices: AM 001-2, 3, 17, 18; AM 001-2 was selected.



AM001 Series
(Metric values in red)
Maximum static load per mount: 3 lbs. (1.4kg)
Maximum dynamic input at resonance: .036 in. (.91mm) D.A.
Weight: .21 oz. (6.0g)
Material: Inner and outer member – aluminum alloy chromate treated per MIL-C-5541, Class 1A

Performance Characteristics

AM001 Series Part Numbers	BTR* Axial net. freq. f_n (Hz)*	Dynamic axial spring rate lbs/in	Dynamic axial spring rate N/mm	Dynamic radial spring rate lbs/in	Dynamic radial spring rate N/mm
AM001-2	17	89	16	74	13
AM001-3	19	104	18	87	15
AM001-4	20	122	21	102	18
AM001-5	22	143	25	119	21
AM001-6	23	164	29	137	24
AM001-7	25	187	33	156	27
AM001-8	27	215	38	179	31
AM001-9	29	247	43	206	36
AM001-10	31	284	50	237	41
	BTR* II				
AM001-17	15	68	12	57	10
AM001-18	17	90	16	75	13
AM001-19	20	117	20	98	17
AM001-20	22	146	26	122	21
AM001-21	25	195	34	163	28

*At 0.36in. (.91mm) D.A. input and maximum static load.
To correct for loads below rated loads use:

$$f_n = f_{nn}\sqrt{P_R/P_A}$$

where

f_n = natural frequency at actual load
f_{nn} = nominal natural frequency
P_R = rated load
P_A = actual load

Figure 2. Data sheet used for design selection of Broad Temperature Range elastomer [3]

3. Implementation

The vibration isolation system was implemented in three different stages. The first stage of vibration isolation is found between the SAITO 180 gas engine and the DUBRO 688 engine mount. The second stage of vibration isolation is found between the DUBRO 688 engine mount and the fuselage of the Sig Rascal. The electric motor used a similar vibration isolation system to that of the second stage. The only difference being a modification to the motor mount to accommodate the difference mounting geometry of the motor to that of the gas engine. The third stage of vibration isolation is found between the TASE gimbal mount and the fuselage of the Sig Rascal. The data collecting method used during the experimental procedure and the three stages of vibration isolation are discussed further in detail next.

The first step to collect vibration data was to prepare the Sig Rascal. First, the Sig Rascal was modified to accommodate the TASE gimbal mount and the vibration isolation systems. Once the vibration isolation systems were installed, the vibration sensor was mounted to the Sig Rascal, next the SAITO 180 gas engine was started and data collection was initiated. Vibration data was collected at different throttle positions. The throttle positions selected were ¼, ½, ¾, and full throttle. The data was collected using the vibration sensor and plotted at a rate of 64 Hz. The same procedure was conducted for the Sig Rascal before the installation of vibration isolation components.

Vibration data for the Sig Rascal at gimbal mounting points were collected before and after vibration isolation. All vibration data was collected using Madge Tech Ultra Shock vibration sensor (Figure 3), with sampling rate of 512 Hz and acceleration frequency response of 0 to 400 Hz. The vibration data collected was recorded at a rate of 64 Hz.

Figure 3. Madge Tech Ultra Shock vibration sensor

3.1 First Stage Isolation

The first stage of vibration isolation is found between the SAITO 180 gas engine and the DUBRO 688 engine mount. This first stage required the modification of the DUBRO 688 engine mount. The engine mount was perforated to create a $\frac{11}{32}''$ diameter hole. The opening was used to insert a DUBRO Elastometric Element 357 on both, the top and the bottom side of the mount. In between the Elastometric element an aluminum tube and a screw where inserted to attach the gas engine to the DUBRO engine mount (Figure 4).

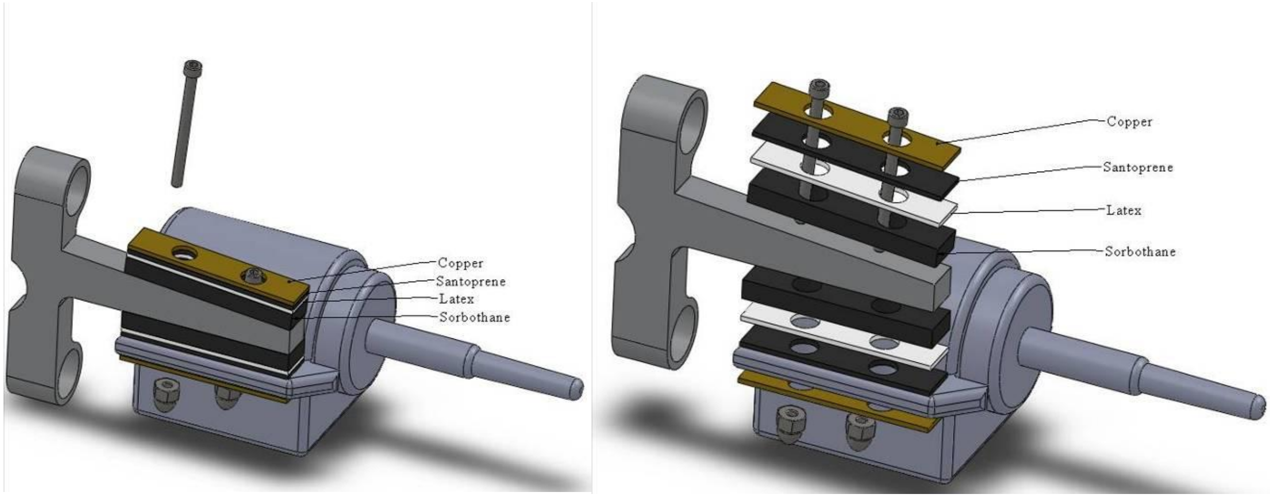


Figure 4. First stage of vibration isolation

3.2 Second Stage isolation

The second stage of vibration isolation is found between the DUBRO 688 engine mount and the fuselage of the Sig Rascal, as shown in Figure 5. This second stage consists of two elastometric inserts that are clamp between the engine mount and the fuselage of the Sig Rascal by a screw and a blind nut. This special engine mount completely separates any metal to metal contact, hence reducing the vibration forces transmitted from the engine mount to the fuselage of the Sig Rascal. A schematic of the DUBRO 688 engine mount is provided in Figure 5.

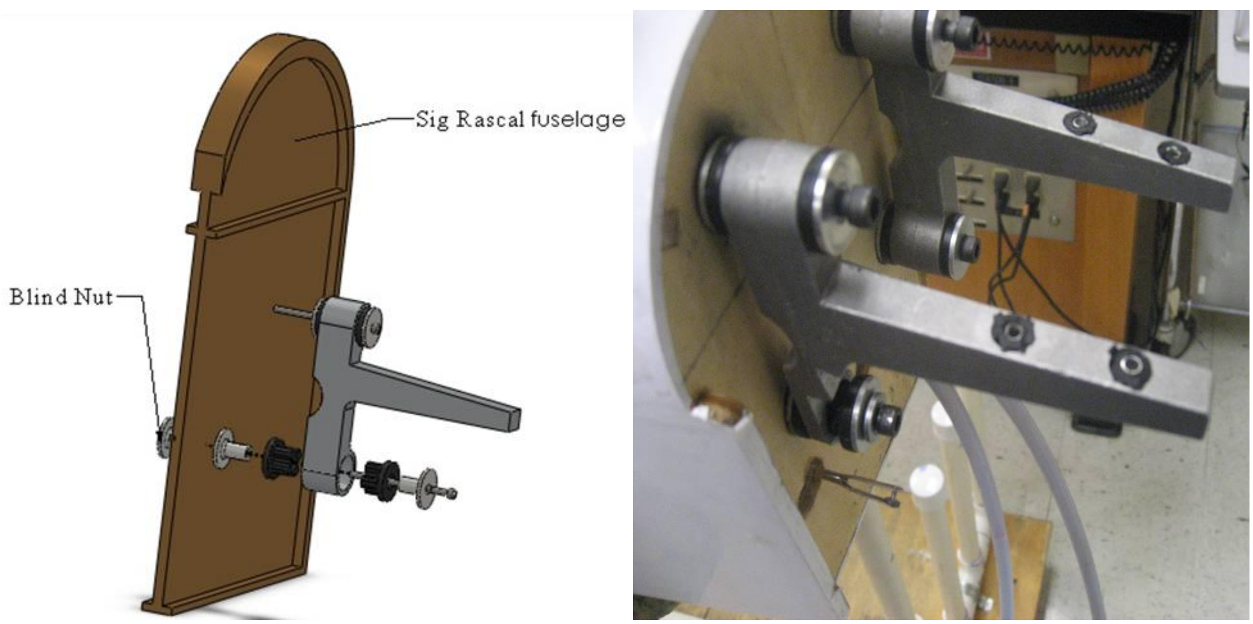
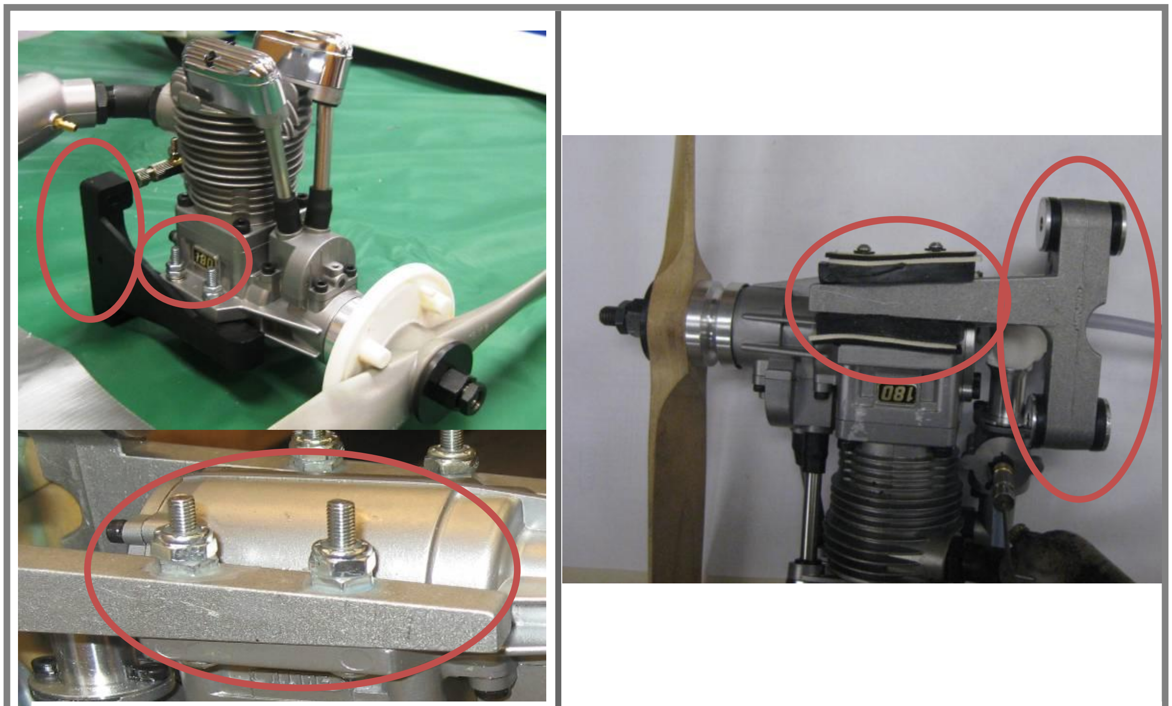


Figure 5. Second stage of vibration isolation



(a) Before (b) After

Figure 6. Stage one and two before and after

Figure 6 above points out the difference in vibration isolation from the original setup to the final setup. In Figure 6, it can be observed how the engine is isolated from the DUBRO 688 engine mount and how the fuselage of the Sig Rascal is isolated from the DUBRO 688 engine mount.

3.3 Third Stage Isolation

The third stage isolates the base vibrations of the Sig Rascal from the TASE gimbal. To be able to accommodate the TASE gimbal, the fuselage of the Sig Rascal was modified. To achieve this, a window was carved through the fuselage of the Sig Rascal (Figure 7a). Next, mounting platforms of plywood were mounted to the fuselage of the Sig Rascal as illustrated in Figure 7b. Finally, the vibration sensor was mounted to the TASE gimbal mount, which in turn was mounted to the Sig Rascal. A set of dead weights of 1.1 lbs were also mounted over the vibration sensor Madge Tech Ultra Shock to simulate the actual weight of the TASE gimbal (Figure 8).

(a) Carved window (b) Plywood mounting platform

Figure 7. Sig Rascal carved window and TASE gimbal mounting points

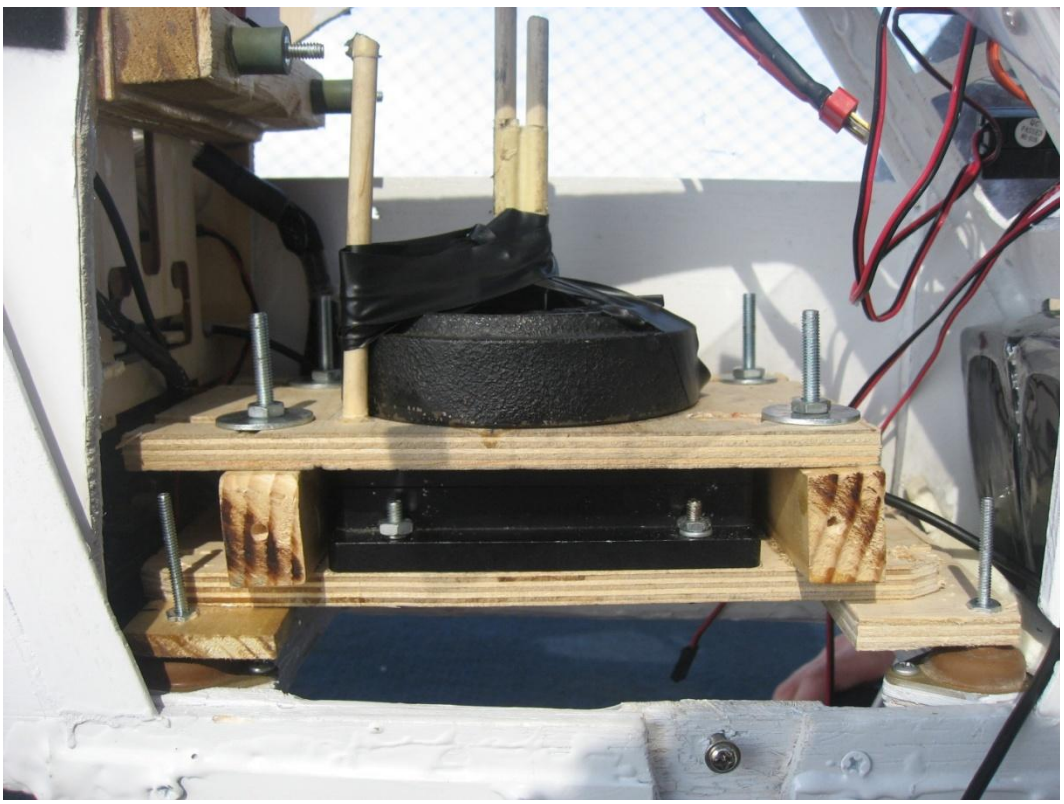


Figure 8. Vibration sensor mount setup

The third stage incorporates BTR elastomer mounts (Figure 9), which were found to be of the optimum material given the base vibrations experienced by the gimbal mount. These special mounts separate the TASE gimbal mount from the Sig Rascal. Four BTR elastomer mounts were used to support the bottom of the TASE gimbal mount, plus two additional soft dampers in the horizontal support beam of the TASE gimbal mount (Figure 10).

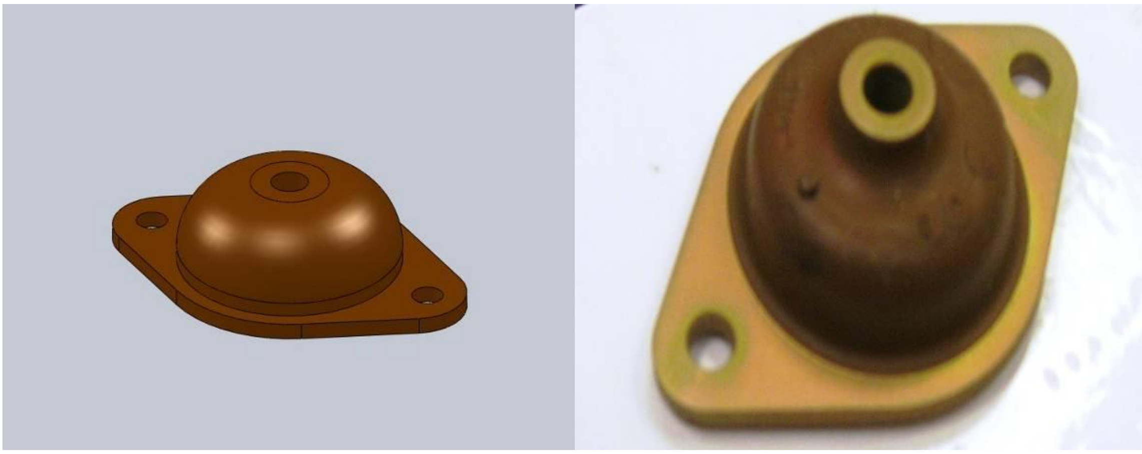


Figure 9. Broad Temperature Range (BTR) elastomer mounts

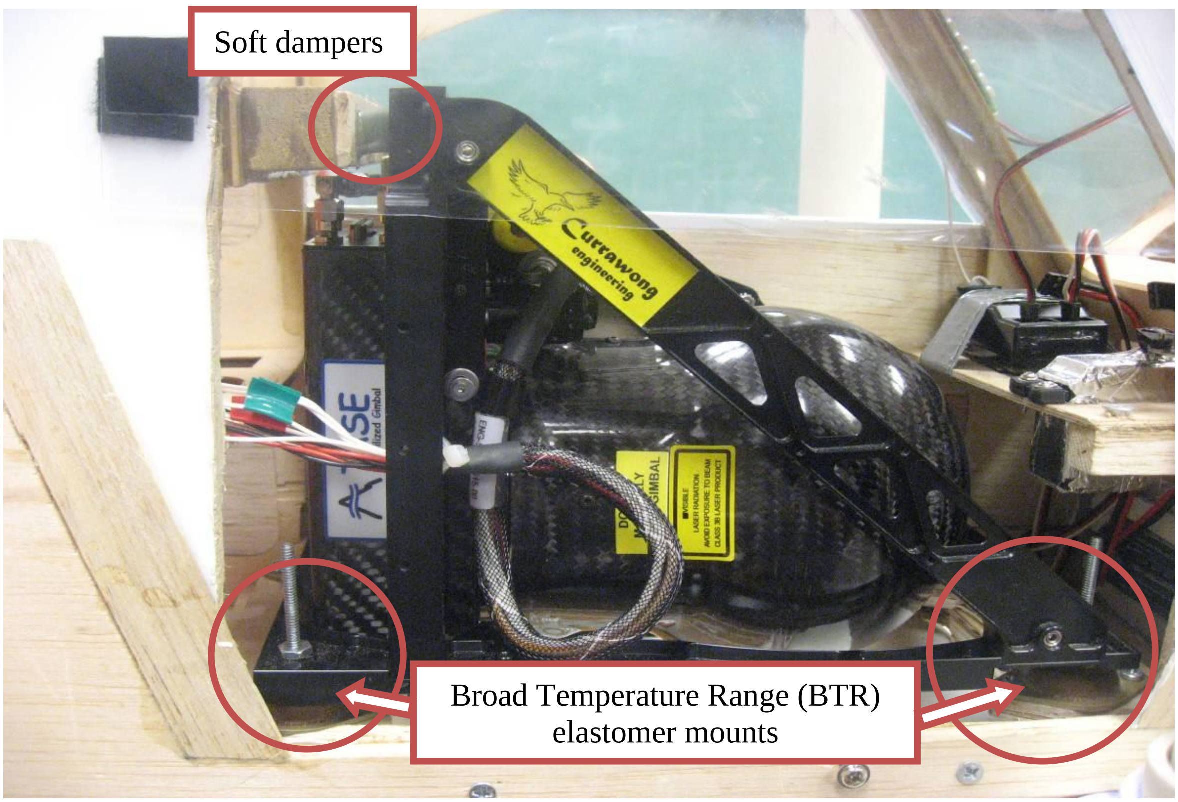


Figure 10. TASE gimbal mount

3.4 Electric Motor Isolation System

The electric motor vibration isolation system is found between the electric motor and the fuselage. A special mount was constructed out of .5 in plywood, to accommodate the motor and the vibration isolation system. This vibration isolation system consists of two elastometric inserts that are clamped between the engine mount and the fuselage of the Sig Rascal by a screw and a blind nut. This special engine mount completely separates any metal to metal contact, hence reducing the vibration forces transmitted from the engine mount to the fuselage of the Sig Rascal. A schematic of the engine vibration isolation mount is provided in Figure 11.

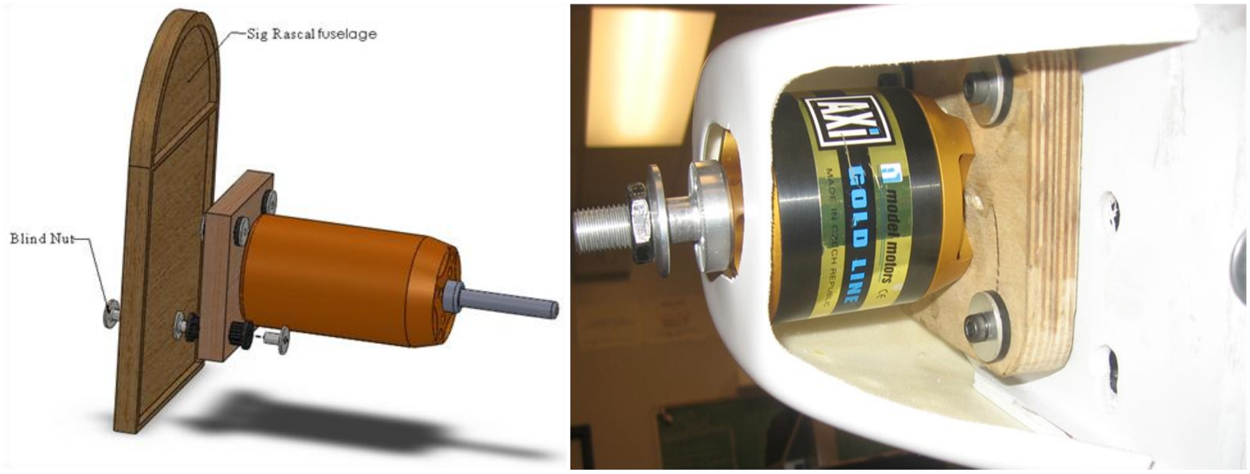


Figure 11. Vibration isolation system for electric motor

3.5 Exhaust Isolation System

The exhaust vibration isolation system suppressed the vibrations generated by the operation of the SAITO 180 gas engine. The vibrations of the engine exhaust were isolated from the fuselage by the use of a soft exhaust deflector. In addition, special consideration was given to the clearance between the fuselage of the Sig Rascal and the exhaust deflector (Figure 12). Furthermore, the muffler was separated from the fuselage by the used of vibration isolation clamps.

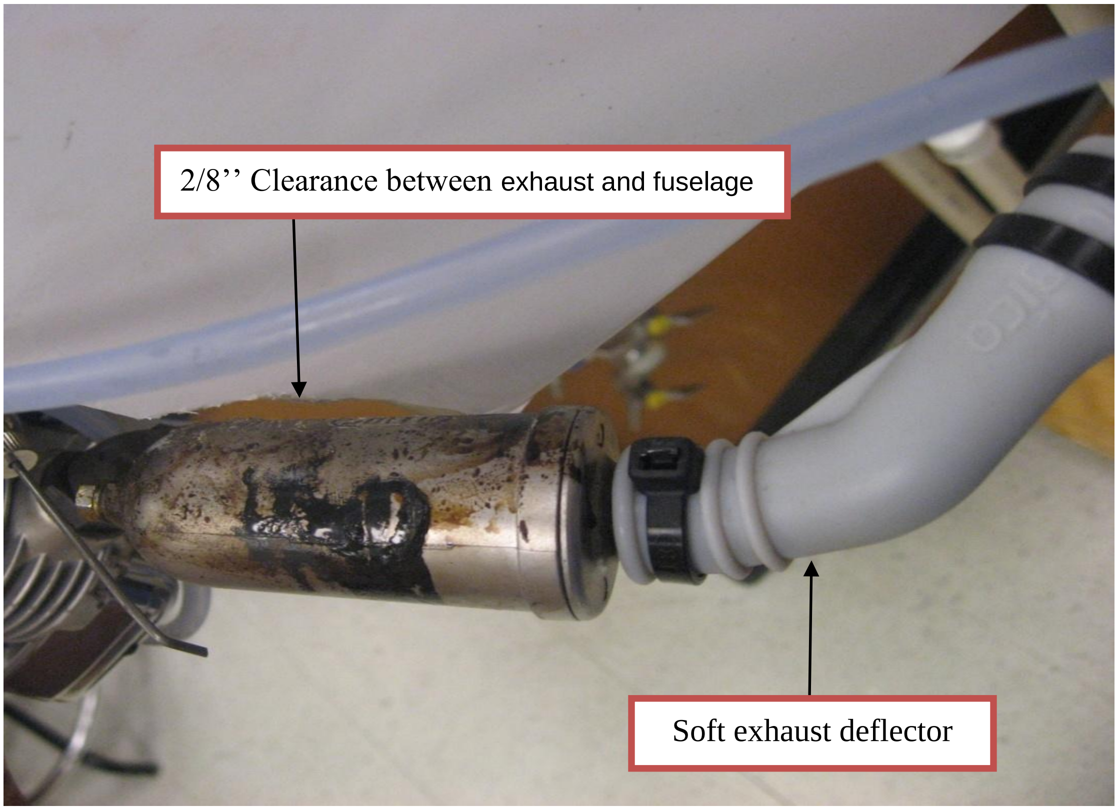


Figure 12. Soft exhaust deflector

3.6 Other Vibration Isolation Considerations

In addition to the three stage isolation system design for the TASE gimbal, consideration was also placed to avoid vibration of moving components. Furthermore, precautions were taken to maintain the integrity of components. This included the installation of lock washers, lock nuts and the application of thread lock to electrical and mechanical components integrated to the airplane.

4. Performance of Isolation System

The first vibration test was conducted prior to the installation and application of vibration isolation components. After the installation and application of vibration isolation components, a second set of data was collected. The vibration sensor was mounted to the gimbal mount which was attached to the fuselage of the Sig Rascal. The magnitude of the data is represented in the dependent axis in terms of response or acceleration in units of gravity ($g = 9.8\frac{m}{s^2}$). The independent axis plots a continuous recording at a sampling rate of 64 Hz of the Madge Tech Ultra Shock vibration sensor.

Figure 13 conveniently provides a comparison and helps to better illustrate the reduction of vibration by the implementation of vibrations absorbing materials and systems. Figure 13 shows that vibration labels were dramatically reduced in all three axes at mission critical speed throttle positions. The vibration labels in the X axis were reduced from 12 g's to 3 g's, for Y axis a reduction from 14 g's to 2.5 g's was observed and for the Z axis vibration labels were reduced from 18 g's to 2 g's. The reductions in vibration labels at the gimbal mounting point permitted all integrated systems in the Sig Rascal to function properly.

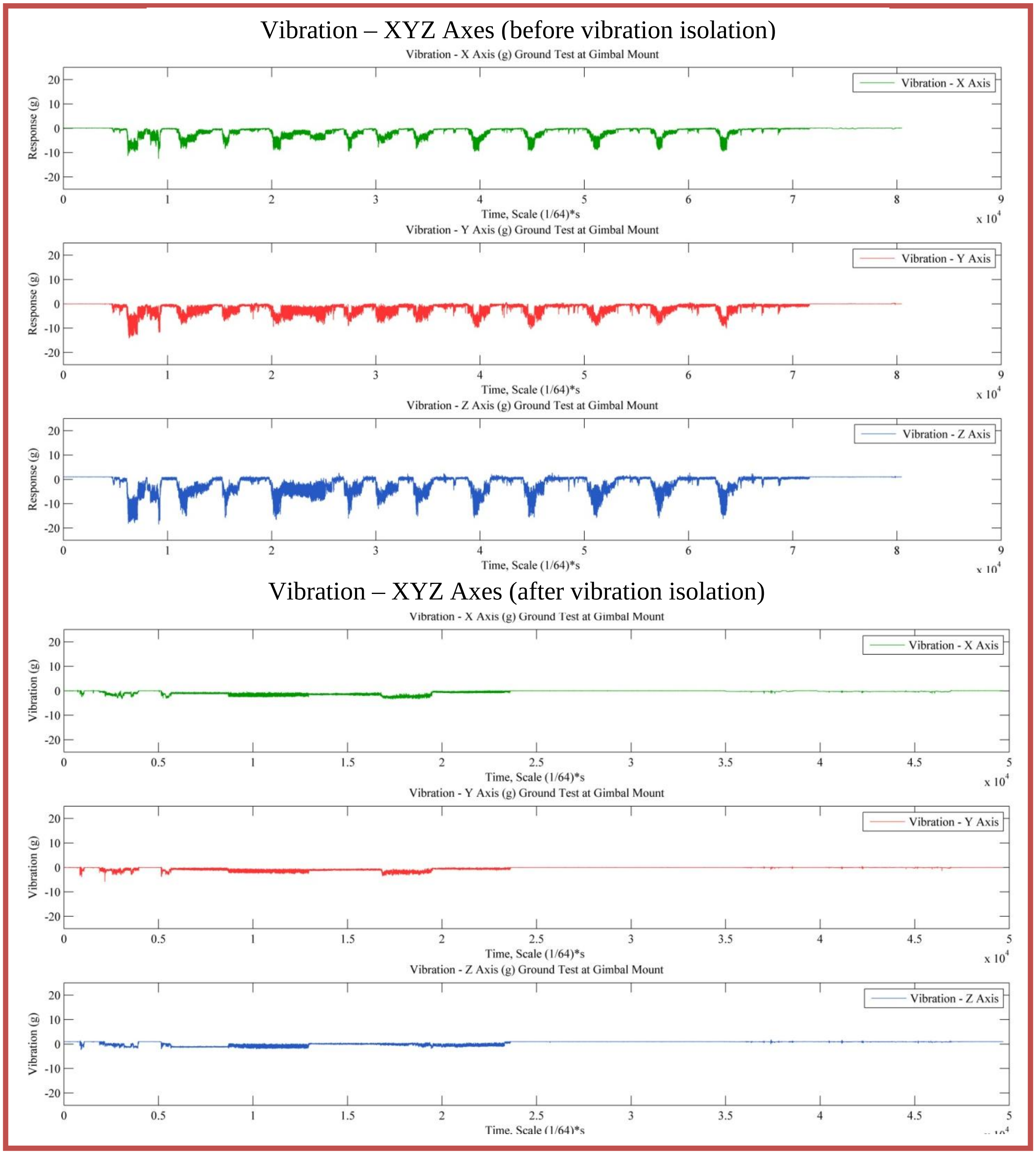


Figure 13. Before and after vibration comparison for X, Y, and Z axis

The final set of data was collected to explore and compare the performance of the vibration isolation system under operation of an electric motor. The vibration sensor was mounted to the gimbal mount which was attached to the fuselage of the Sig Rascal. The magnitude of the data is represented in the dependent axis in terms of response or acceleration in units of gravity (g = $9.8\frac{m}{s^2}$). The independent axis plots the continuous recording at a sampling rate of 64 Hz of the Madge Tech Ultra Shock vibration sensor. The AXI electric motor was run at all throttle positions during the course of the vibration test. The vibration experienced by TASE gimbal for X, Y and Z axis were in general below 2 g's, with the exception of a few shock spikes. The shock spikes are derived from the automatic brake control integrated into the AXI electric motor. The automatic braking stopped the rotation of the propeller abruptly and almost instantaneous while throttling down; hence, creating the shock spikes.

Finally, Figure 14 allows for a convenient performance comparison of the vibration isolation systems between the two power systems. The first power system illustrated is the SAITO 180 gas engine, followed by the AXI 5345/14 electric motor. The comparison between the SAITO 180 gas engine and the AXI 5345/14 electric motor power system show that the vibration isolation system can perform satisfactory under both power systems. However, it is noticeable that under the electric power system, the vibrations can be further reduces by about 1 g. The great advantage of the electric motor is that the vibration labels are reduced to about 2 g's or less at all throttle positions, which is not the case for the gas engine that needs to operate between $\frac{3}{8}$ and $\frac{5}{8}$ throttle range for the vibrations labels to be acceptable. One disadvantage of the electric motor is that increases electromagnetic interference (EMI), which significantly reduced the radio control communications between the transmitter and the receiver of the Sig Rascal.

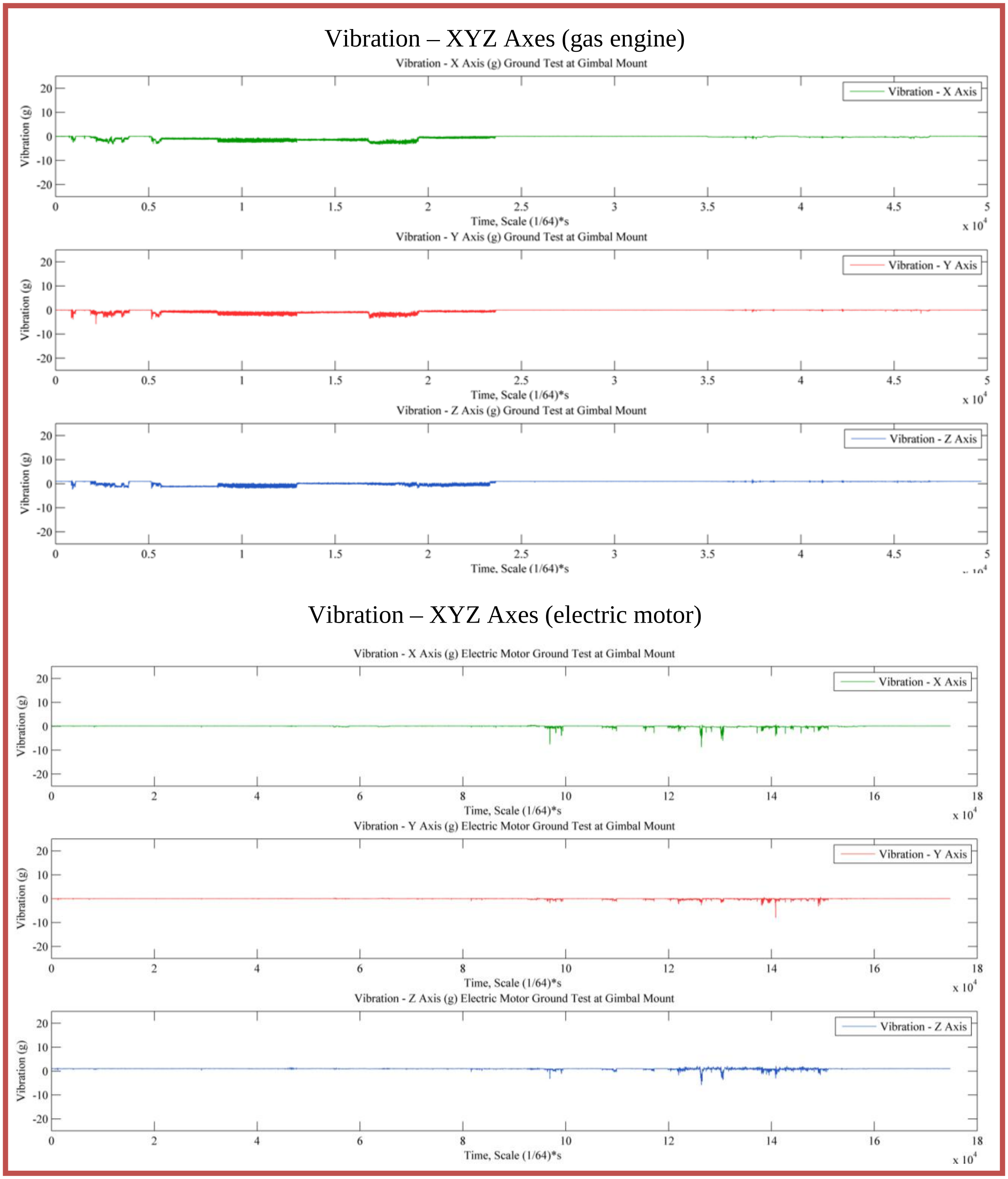
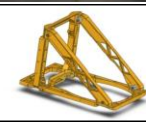


Figure 14. Gas engine vs. electric motor vibration comparison for X, Y and Z axis with vibration isolation mounts

5. Cost analysis and Devices

The Unmanned Aero Vehicle Targeting System project founded by Edwards Air Force Base, USAF had a total budget of $100,000 dollars for the first phase. However, the budget for the vibration isolation system was of $5,000 dollars. Table 1 present the list of devices and components that is pertinent to the vibration analysis section of the UAV Targeting System project.

Table 1. List of Devices

Part	Price per unit	Quantity	Illustration
Sig Rascal • Wingspan: 110 in • Length: 75.75 in • Payload: 15 lbs	$400.00	3	
Gimbal Mount Frame	$1,500.00	1	
Madge Tech Ultra Shock Vibration Sensor • Sampling rate: 512 Hz • Accelerometer freq. resp. : 0 to 400 Hz • Recording Interval: 64 Hz -5 min.	$800.00	2	
DUBRO 688 Gas Engine Mount	$38.00	3	
BTR Elastomers	$76.00	6	
DUBRO Elastometric Element 357	$9.20	4	
SAITO 180 Gas Engine • Type: 4 stroke, single cylinder • Displacement: 1.8 cu in • Horse power: 2.8 Hp • RPM range : 2,000 – 10,000 RPM • Weight: 2.21 lbs	$460.00	1	
AXI 5345/14 Electric Motor • RPM/V: 225 RPM/V • Current capacity: 110 A/20 s • Weight: 31.6 oz • No. of cells: 8-12 LiPo	$350.00	1	
TASE DUO gimbal • Slew rate: 200°/sec • Pointing resolution: 0.05° • Weight: 2.34 lbs	$40K	1	
Miscellaneous (Hardware, Other Materials)	$500.00	1	

6. Conclusion

The vibration data collected before and after vibration isolation shows that the vibration experienced by the TASE gimbal is significantly reduced. After installation of shock and vibration absorption materials, vibration loads to the TASE gimbal mount were reduced to less than 3 g's for the X, Y, and Z axis. The reduction in the vibration load transmitted is very important for this specific project application because it allows the accelerometers, gyros and GPS to acquire accurate data and to operate efficiently; hence, greatly reducing the margin of error to calculate the position vector of the Sig Rascal. In addition, lower force and vibration transmitted to the TASE gimbal provides a more stable platform for the laser targeting system. Reduction of vibrations for the TASE gimbal means less movement in the laser targeting system, therefore providing less displacement deviation from the laser to the target, especially at greater distances from the laser targeting system. The comparison between the SAITO 180 gas engine and the AXI 5345/14 electric motor power system show that the vibration isolation system can perform satisfactory under both power systems. However, it is noticeable that under the electric power system, the vibrations can be further reduces by about 1g. The results of this study suggest that passive vibration isolations systems can effectively be implemented by the use of multiple vibration isolation systems and the proper selection of materials currently available.

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Fountain Bench – A Hydraulic Apparatus for Formal and Informal Science Education

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Abstract

The Fountain Bench is a new modularized and portable apparatus that has been developed and put to use for the purpose of demonstrating several water flow cases. The goals of using the apparatus are to enhance presentation of course material in a Fluid Mechanics course and to assist in informal education provided to younger students and the general public attending university events. Three flow cases developed so far are a bathtub vortex, a water bell, and a wet wall, but more can be added later. Each of these demonstrations has scientific significance but also has been used by artists as the focal point in water features with special effects. This paper provides a detailed description of the apparatus and examples of how it has been used so that interested readers can build the apparatus for their own use. The materials and equipment cost $1600.

Background

Several learning styles surveys, conducted in our CIVL 130 - Introduction to Fluid Mechanics, have indicated that Pacific engineering students have a strong preference for hands-on and visual learning. Current research in engineering education has shown that students' learning and their ability to retain concepts is enhanced when different learning styles are addressed, including the use of visual teaching aids[1, 2].

The Introduction to Fluid Mechanics is a 4-credit core course for four of the seven engineering majors at Pacific, and has a laboratory associated with the course. The laboratory has a number of experiment setups, ranging from small table-top units to measure fluid properties to an 18-foot water flume to study open channel flow phenomena. These experiments are augmented with in-class demonstrations used to help students visualize concepts presented in the class. Examples of these visual-aids and the concepts they demonstrate include:

- Marbles dropped in columns containing different fluids – effects of fluid viscosity on motion
- Super soaker jet used to move an object – conservation of momentum
- Different types of pumps and valves – physical models of hydraulic machinery and fittings used in fluid distribution systems

Students are asked to apply concepts learned in class to explain or prove why a certain demonstration works the way it does, or to predict how a change in one characteristic will change the resulting system behavior. Experiments and demonstrations help to clarify concepts and they allow students to apply theory to practical examples similar to those they may encounter in engineering practice.

However, some of the topics taught in CIVL 130 do not have an associated experiment or demonstration. We are always seeking additional instructional setups to enhance learning and to increase the laboratory capabilities. One component of the lab is an experiment design project that allows students to demonstrate and test topics discussed in the class. The Fountain Bench was developed with this need in mind and as a demonstration of what the students can develop for their project. Examples of fluids-related demonstration units developed by others can be found in the proceedings of the ASEE annual conferences, available online at asee.org[3-5].

Objective and Desired Outcomes

The goal of developing the Fountain Bench was to provide a dual-purpose apparatus for use in formal and informal fluid mechanics education. Specifically, the apparatus can be used for formal demonstration of fluid mechanics concepts to augment class discussions and to informally educate younger students (K-12) and the general public about the science and beauty of fluid motion used in water features. Additionally, the apparatus could be used as a platform to experiment with design ideas for senior design projects, for example, in the area of innovative water features.

Desired outcomes of the Fountain Bench project are:

- Enhanced tools for hands-on learning in CIVL 130,
- Increased student and public interest in science and engineering,
- Increased awareness of the engineering involved in design of water features with special effects.

A detailed description of the Fountain Bench apparatus, its configuration, and the nature of demonstrations are presented in the next section.

Fountain Bench Apparatus

To meet the dual-purpose nature of the Fountain Bench, the flow cases demonstrated were required to be (a) technically significant, to serve students of fluid mechanics, and (b) visually attractive, to excite and capture the attention of K-12 students and the general public. To satisfy these criteria, the three flow cases selected for initial implementation were a bathtub vortex, a water bell, and a wet wall. Each of these cases has been the subject of scientific investigations because of its applications in science and engineering. Each has also been incorporated in the design of water features presented as works of art. Although it is not the purpose of this paper to provide details about the scientific and artistic aspects of the demonstrated flow cases, sources of additional information for interested readers are listed in Table 1. Included in the table are references from the scientific literature highlighting review and classic papers together with articles from popular magazines that offer do-it-yourself kinds of projects. Web sites that contain information on relevant water features with special effects are also included.

Table 1. Scientific and artistic references for the flow cases included in the Fountain Bench.

Flow Case	Descriptions	Scientific References*	Artistic References
Bathtub Vortex	Water drains from a vessel, creating an air-core vortex at the drain. This is called a bathtub vortex or whirlpool.	6 C 7-9 G 10 R 11 T	Artist William Pye has created large size (6ft diameter) works of art with the bathtub vortex as the principal feature. www.williampye.com
Water Bell/Sheet	Water jet impacts a disk, forming a sheet or a bell depending on jet properties.	12 C 13 G 14 R	Nozzles that form water sheets and bells are marketed by different companies. Inexpensive ones are available at home improvement centers.
Wet Wall	Water streams down a vertical surface, creating ripples and other instabilities.	15 G 16-17 T	Wet walls have been popular water features in recent years. For example, view different styles at www.waterfallswaterwalls.com

**Numbers in column 3 correspond to references at the end of the paper. Abbreviations following the numbers are defined as C = classic article, G = general interest reading that includes do-it-yourself components, R= review article, T = technical paper.*

The Fountain Bench is a portable and modularized apparatus made of two parts, (a) the stand that includes a water reservoir and a pump, and (b) the three modules (i.e., flow cases). This modular design allows for expansion of the number of flow cases demonstrated by the apparatus. New modules can be developed and added to increase the educational value of the apparatus. The total cost of materials and equipment for the apparatus was $1600 (in 2008). The apparatus was fabricated in-house by the school’s technician. Although such an apparatus does not exist commercially, similar educational tools are marketed in the range of $10,000 or higher. A summary of the materials and equipment costs is provided in Appendix A. Interested readers may contact the authors to obtain shop sketches for the apparatus, although photographs of the apparatus that follow with the given dimensions in the text should provide sufficient details.

Each module can be set up separately on the top of the stand. Two surplus double-walled soft drink coolers were repurposed as reservoirs for this project, so that two modules could be set up and demonstrated simultaneously. The bathtub vortex and water bell modules are shown in operation side by side in Figure 1. Descriptive text and graphics attached to the sides of the stand, as shown in Figure 1, enhance its educational value and attractiveness. The posters, also shown in Appendix B, can be displayed adjacent to, or attached to the front of, each stand.

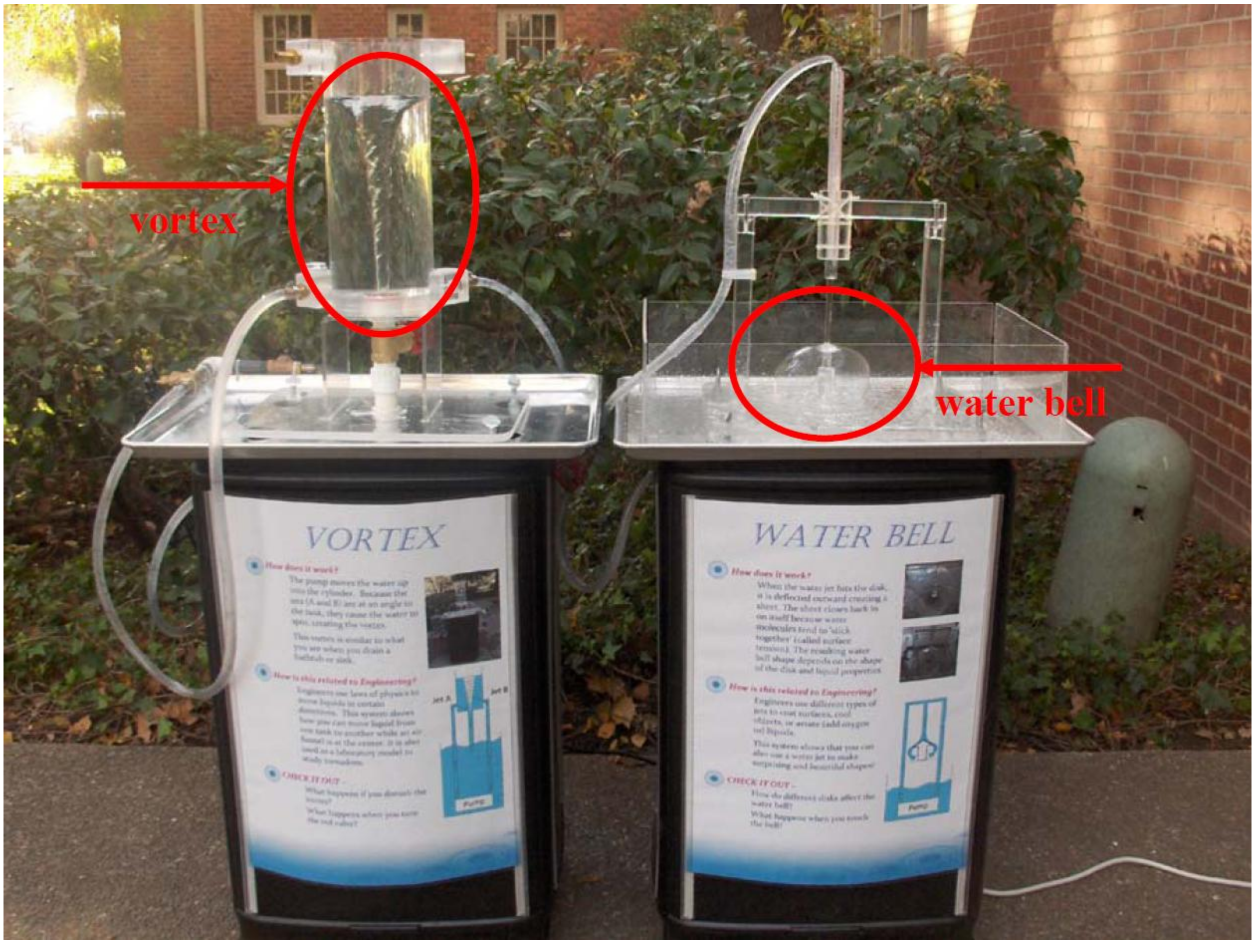

Figure 1 – Bathtub vortex module (left) and water bell module (right). Base (reservoir): 35"H x 20"W x 16"D. Reservoir plus module: 58"H x 26"W x 18"D.

The stand/water reservoir has a usable capacity of about 12 gallons and comes equipped with caster wheels so it can be moved easily by one person, even when filled. Water is supplied to the module by a submersible pump (rated 110V, 3.5A) via 1/2in plastic tubing. One 2in diameter hole and one 1/2in diameter hole are drilled on the reservoir side walls to allow access for a power cord and plastic tubing. The reservoir's open top is covered by an aluminum tray (26in x 18in x 1in deep) that in turn supports the module. Two wooden cleats, one with two rounded corners and the other with sharp corners, are attached with screws to the underside of each tray to hold the tray in place. The cleats provide a one-way fit between the tray and reservoir. A central hole (2in diameter) in the tray allows water to drain back into the reservoir. A standard sink drain was installed in the center of the tray to cover the sharp edge of the hole. A separate drain spigot, located near the base of the reservoir, can be flipped open to empty the reservoir.

Each of the three modules, the vortex, water bell, and wet wall, is described below.

Vortex Module

This module, shown in Figure 2, demonstrates the bathtub vortex. The vortex is created when water with even a small angular momentum drains from the bottom of its container.


Figure 2. The bathtub vortex module.

The bathtub vortex has been studied for over 50 years and is considered to be a laboratory model of a tornado. The vortex module constructed for the Fountain Bench apparatus consists of an acrylic cylinder (6in diameter, 15in high) with four tangentially drilled holes (1/2in diameter) that serve as inlets – two located near the top and two near the bottom. Each inlet has a 1/2in barbed fitting. One or all inlets can be used simultaneously; however, typically just a pair of inlets - either the ones on the top or the ones at the bottom - is sufficient. The inlets not used are closed off, for example, by a short length of plastic tubing bent and secured by a spring clip. A 1in diameter hole in the center bottom serves as the drain hole. The hole is machined such that different shaped outlets can be inserted for experimentation. The inserts include sharp edged, bell mouth, and raised outlets. The outflow rate is regulated by a globe valve fitted below the drain hole. The cylinder sits on the top of an inverted U-shaped acrylic platform, which is glued to the base plate (6in x 6in x 6in, 1/4in thick). The base plate has four leveling screws, and a bubble level is glued onto the plate so that the user can level the module. A piece of 1in PVC pipe extends below the globe valve and fits snugly in the drain in the aluminum tray. The water is supplied to the inlets via 1/2in plastic tubing and is regulated with three globe valves – one for the main line and two for the inlets. These valves and the associated plastic tubing are located at the right side of the aluminum tray, partially shown in Figure 2. A rotameter (not visible in the figure) is attached and can be used to measure the flow rate.

Water Bell Module

When a vertical water jet impacts a solid surface (called the impactor) of similar diameter, the water spreads out and forms a surface resembling a bell at certain flow rates; a mushroom cap at higher flow rates. Factors that determine the shape of the water bell are the flow rate, surface tension, pressure differential between inside and outside of the bell, and gravity. Water bells and sheets have been studied since 1833 by scientists and engineers. Today, significant practical applications that motivate the study of such a flow case include atomization and coating applications. The water bell module, shown in Figure 3, provides a platform to create water bells and mushroom caps of different sizes and shapes.

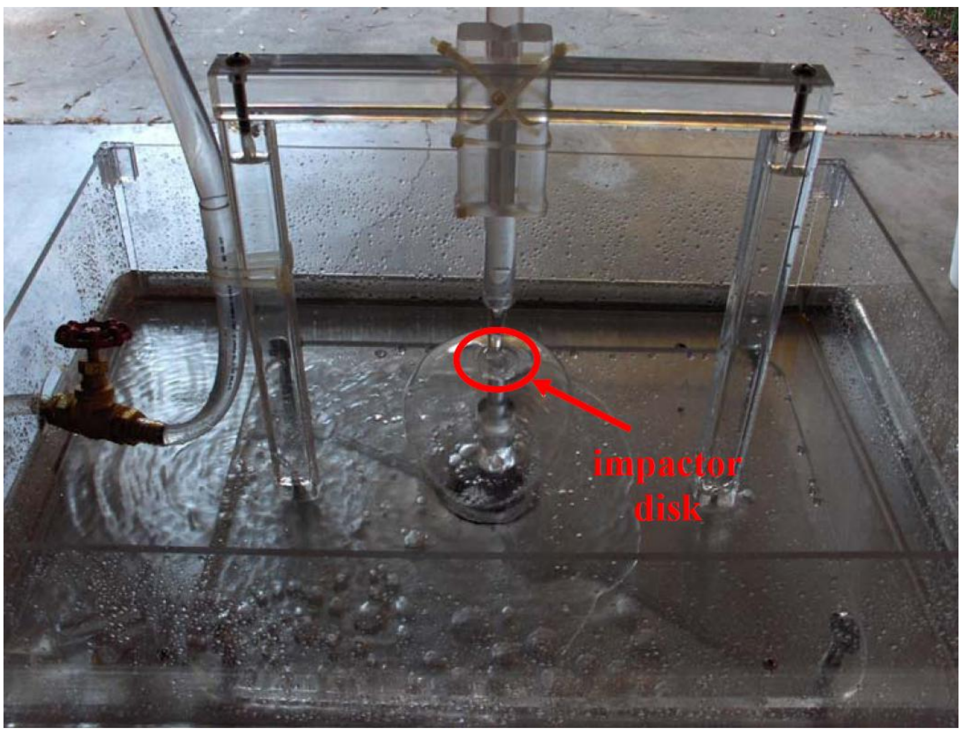

Figure 3. Water bell module with the splash guard. The impactor shown by the arrow is a 1in flat disk.

The module is made of an inverted U-shaped frame (made of 1.5in acrylic square rod) attached to a base plate (16in x 12in x 1/2in thick). The base plate has a bubble level and four leveling screws. The frame supports a length of 1/2in flexible plastic tubing. The last 12 inches of the tubing are inserted in a rigid plastic pipe, which is vertically attached to a sliding bracket on the horizontal section of the frame. This arrangement allows fine positional adjustments of the water jet. The jet flow rate is adjusted with a globe valve, seen on the left side in Figure 3. At the center of the base plate, a cylindrical post holds the impactor plate. Several impactor plates are available for experimentation, as shown in Figure 4. To prevent splashing, a guard, made of four thin Plexiglas sheets attached together by plastic corner clips, is placed in the tray and around the water bell module (splash guard overall dimensions: 23in x 16in x 6in high).

Figure 4. Impactors shown from left are: a flat disk, cones of different angles, and the red concave impactor in the holder. The impactor diameter is 1in.

The results of experimentation with the flat disk impactor at three different flow rates are shown in Figure 5. Sometimes the bell shape is unstable and disturbing the bell surface (for example, by poking it with a finger) can suddenly change the size of the bell. This curious behavior is caused by equalizing pressure on the two sides of the bell, and it is very interesting for students to test and observe.

Students can change the diameter of the bell by adjusting the valve. The diameter of the bell increases as the flow rate is increased, but the bell surface remains continuous and even regains its shape after it is poked or otherwise disturbed. At the same time, students can be introduced to the effects of fluid surface tension, for example, by counting the number of water drops that can be placed on a penny and measuring capillary rise in a small-diameter tube. Although development of the theory underlying the water bell module is beyond the scope of an introductory Fluid Mechanics course, the module can be used to demonstrate a different application of fluid surface tension.

Figure 5. Water bells created by 1in flat disk impactor. From left to right, low, medium and high flow rates. Scales not the same in the three photographs.

Water bells created with conical and concave impactors are shown in Figures 6 and 7, respectively. When the concave impactor is used, a concave water sheet is produced, as opposed to a bell-shaped form. This sheet disintegrates into droplets at a radius that increases as flow rate increases. Two such sheets are shown in Figure 7. It seems possible to create sheets with interesting profiles by machining grooves or ridges on the edge of the concave impactor. For example, addition of a tiny round protrusion on the edge of a concave impactor can produce a heart-shaped sheet.

Figure 6. Water bells created by two different conical impactors. The bell size does not drastically change as flow rate is increased.

Figure 7. Water sheets produced by a concave impactor; effect of higher flow rate shown on the right.

Wet Wall Module

A wet wall is a vertical surface over which water flows down due to the effect of gravity. Water is supplied through small holes drilled along the length of a pipe (called a manifold) located at the top of the vertical surface. Fountain designers have utilized this simple idea in a variety of scenarios utilizing different materials and spanning a wide range of sizes, from table top decorative fountains to multi-story high water features in public spaces.

Two versions of the wet wall module were fabricated and are shown in Figure 8. The first set up holds only one "wall" (17in wide x 11in high) and the second one holds two smaller "walls" (10in high x 7in wide each) side by side. This second set up allows the user to see the water flow over two surfaces with different surface textures at the same time. The single-wall module is made of an acrylic frame (made of 1.5in square rod, 12in high x 18in wide) glued to a base plate (12in x 24in x 1/2in thick). Each of the vertical sides of the frame has a groove to allow easy mounting of the wet wall. Four leveling screws and a bubble level on the base plate allow the user to level this module. The manifold, attached to the horizontal bar of the frame, has a series of 1/16in holes drilled along its length. The manifold is connected to the pump via 1/2in plastic tubing and a globe valve is used to adjust the flow rate. The double-wall module has a similar construction but the frame has three vertical supports to accommodate the two walls and its base plate is smaller than the single-wall module (1.5in x 20in x 1/2in thick).

Figure 8. The wet wall module, single-wall on left, double-wall on right.

As shown in Figure 9, a variety of flow patterns can be generated over the wet walls using different flow rates and different surface textures.

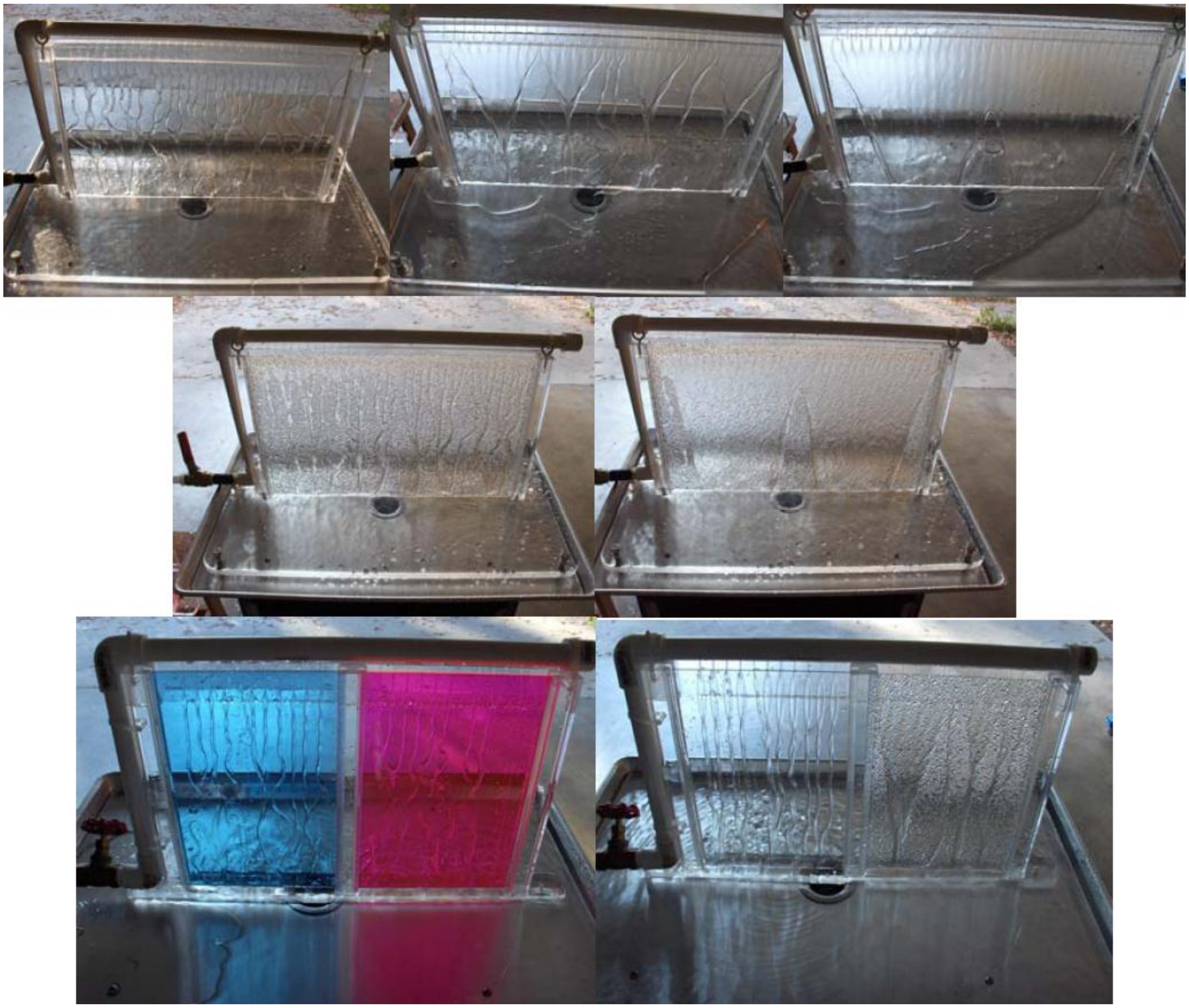

Figure 9. Water patterns on smooth wet wall (first row), rough wet wall (second row) with increasing flow rate from left to right. The third row shows smooth but colored wet walls on the left, and smooth and rough wet walls on the right.

Use of the Modules for Outreach and Class Demonstrations

We have used the three modules at several public and outreach events. These include Pacific Preview Day, an Open House-type event held for prospective students and their families, and for demonstrations for students visiting from local K-12 schools. The modules were also demonstrated at Expanding Your Horizons (EYH), an annual conference and workshop hosted by the Society of Women Engineers to introduce girls to Math, Science, and Engineering. Several hundred girls in grades 6-12 attend EYH each year and participate in hands-on workshops throughout the day. Figure 10 shows a group of girls intently observing the water bell module on their way to the lunch room.

Figure 10. Expanding Your Horizon participants look at water bell module.

The modules were also used in the Introduction to Fluids Mechanics course. The first day of the Fall 2009 semester was a Tuesday - when the labs meet - but before the class had actually met. Rather than cancelling lab for that day, the modules provided an excellent tool to “Shock and Awe”[18] the students to get them excited about the course and to introduce them to potential ideas for projects they would develop during the semester. The vortex and bell modules were in operation as students entered the lab and students and the instructor spent approximately 20 minutes discussing each set up. The instructor asked students to think about how the set up works by asking questions such as “Where is the water coming from?”, “How does the water get up into the vortex tank?”, “Why does the vortex form?”, “Why is the bell shaped like a bell, and not a flat sheet?”, and so on.

This demonstration and discussion served several purposes. First, the demonstration was used to get students excited about the course: instead of the usual 30 minutes spent covering policies and procedures, students were introduced to concepts they would learn about during the semester including fluid properties, conservation of mass, energy, and momentum, and turbomachinery. Second, the format provided an opportunity for students to meet one another and for the instructor to learn students’ names. Students self-selected into groups of two and were asked to work with someone they did not already know well. The students had to discuss each question and formulate an answer. A different group was called upon to answer each question and the students had to introduce one another before answering. Finally, for those students who have a preference for inductive learning (seeing the example first, then inferring principles)[19], visual and active learning, the demonstration provided them with a visual reference that they could refer back to throughout the semester when covering different topics.

Evaluation

To date, the effectiveness of the Fountain Bench apparatus as a learning and outreach tool has only been assessed on a qualitative basis. The hands-on demonstrations to girls attending the EYH workshop and K-12 students visiting campus have received very enthusiastic responses. Children love to play with the water, taking turns to disrupt the bell or drop things into the vortex (e.g., a ping-pong ball) and observe the effects.

Demonstrations performed in the Fluid Mechanics lab were also well-received. Students were actively discussing, answering, and asking questions. Even those students who were generally disappointed about the prospect of having a lab before the class had even met, made positive comments about their expectations for the course immediately after using the Fountain Bench. When the course is taught again in Fall 2010, student learning will be assessed more formally by having each student complete a questionnaire on all 3 modules before the class discusses any of them. The class discussion will focus on two of the three modules, and the students will be asked to submit revised answers about all three modules after the class discussion. We anticipate that the Fountain Bench will be used frequently in the fluids lab to enhance students' learning and at events held for K-12 students and the general public to show them how beautiful and interesting fluid flows can be!

Acknowledgements

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Appendix A – Summary of Materials and Equipment Cost (in 2008)

Equipment	
Submersible pump, $160 each, need 2	$320
Reservoir, fitted with inlet, discharge valve, etc.	$100
Variable area flow meter	$ 90
Brass ball valves, $10 each, need 5	$ 50
Utility cart, modified with 10” pneumatic tires	$350
Materials	
Plexiglas stock	$250
cylinder, 6”OD	
sheet, ½”thick	
rod, 11/2” squared	
PVC pipe, fittings, glue, brackets	$ 50
GFCI outlet, wires, connectors, box	$ 50
Plastic flexible tubing, ¾”, ½”	$ 30
Miscellaneous hardware, fasteners, etc.	$100
Shipping and tax, 15%	$210
Total	**$1,600**

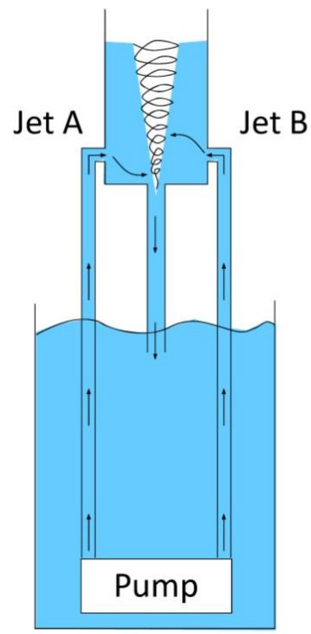
Appendix B – Posters Attached to the Apparatus

VORTEX

How does it work?

The pump moves the water up into the cylinder. Because the jets (A and B) are at an angle to the tank, they cause the water to spin, creating the vortex.

This vortex is similar to what you see when you drain a bathtub or sink.



How is this related to Engineering?

Engineers use laws of physics to move liquids in certain directions. This system shows how you can move liquid from one tank to another while an air funnel is at the center. It is also used as a laboratory model to study tornadoes.

CHECK IT OUT –

What happens if you disturb the vortex?

What happens when you turn the red valve?

WATER BELL

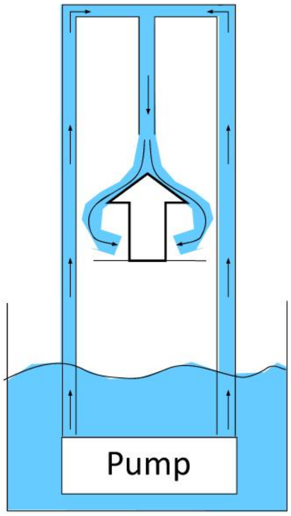
How does it work?

When the water jet hits the disk, it is deflected outward creating a sheet. The sheet closes back in on itself because water molecules tend to 'stick together' (called surface tension). The resulting water bell shape depends on the shape of the disk and liquid properties.

How is this related to Engineering?

Engineers use different types of jets to coat surfaces, cool objects, or aerate (add oxygen to) liquids.

This system shows that you can also use a water jet to make surprising and beautiful shapes!



CHECK IT OUT –

How do different disks affect the water bell?

What happens when you touch the bell?

WET WALL

How does it work?

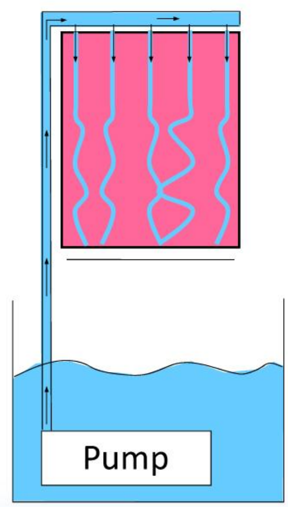
Water from jets directed at an angle to the smooth wall tend to stick to the wall and to each other because water has surface tension.

The wall roughness can change the flow pattern - the jets will follow a different path and bunch together.

How is this related to Engineering?

Engineers use different techniques to coat surfaces in industrial applications. It is important to know how moving fluids interact with surfaces.

This system shows how a small disturbance can create a different pattern than what you'd expect!



CHECK IT OUT –

What happens to the jets if you change the flow rate or tilt the wall?

Using Design, Build, Fly Projects to Provide Life Lessons in Engineering

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This paper recounts the methods applied in a senior design course taught at Embry-Riddle Aeronautical University (ERAU) in Prescott, Arizona. It will discuss the life lessons provided via design, build, fly (DBF) projects which allow students to experience competition and collaboration as part of the same year-long project.

The capstone sequence at ERAU consists of Preliminary and Detail Design courses in both the Aircraft and Spacecraft tracks. In the Aircraft track, students in the Preliminary course form design teams which are given a choice of projects defined by Request for Proposals (RFP's). Two teams select an RFP suitable for design of an aircraft which can be fabricated as a flight test article in the Detail Design course. These two teams then create independent designs to be further refined in Detail Design. The two competing teams then become 'design groups' as a part of a single team in Detail Design. Each group fabricates a scaled model for the purpose of collecting aerodynamic data via wind tunnel testing. This testing is completed within the first six weeks of the semester, allowing a faculty panel to select the design which has the highest likelihood of success as a flight test article based on the wind tunnel test results. The two design groups then combine their efforts toward the collaborative design and fabrication of a radio-controlled aircraft representative of the down-selected concept which is structurally tested and optionally flight tested later in the semester. The flight test is optional to allow course compatibility with design teams that choose to pursue non-DBF design options.

This paper begins by explaining the context that led to the incorporation of the DBF option in the Aircraft Detail Design course, followed by a description of the chronological sequence of events which guided this curricular change. Descriptions of the life lessons experienced by the students are then provided. These lessons are formed while students are working with their former competitors and, for one of the design groups, in the disappointment of leaving their design behind and working on the design and fabrication of their competitor's concept during the final two months of the semester. This paper will conclude with an evaluation of the success of the program and a discussion of how the DBF projects allow ERAU to better meet ABET design objectives, followed by suggestions as to how the program has and will be further improved based on lessons learned.

Context

ERAU/Prescott is a 4-year university in Northern Arizona with an enrollment of approximately 1,600 undergraduate students. The most popular engineering degree program is Aerospace Engineering (AE). Within the AE curriculum, there is a strong emphasis on laboratory and design work to prepare the students for senior capstone design courses.

Students majoring in AE must choose one of two design tracks: aircraft or spacecraft. The aircraft track culminates in a sequence of two (2) senior design courses: Aircraft Preliminary

Design and Aircraft Detail Design. Likewise, the spacecraft track also has two (2) senior design courses: Spacecraft Preliminary Design and Spacecraft Detail Design.

In each of the Preliminary Design courses, students work in teams to design a conceptual aircraft or spacecraft from the ground up. These craft may be designed in response to a set mission statement (e.g., in response to the yearly AIAA design competition) or according to the interests and objectives of the student teams and instructors. In the Detail Design courses, each team selects one (1) component or set of subsystems from their craft—a wing section, a tail section, a satellite tracking system—and creates scaled models that they then subject to various tests, such as wind tunnel, vibration, and static structural tests. These test results are then compared to computer-based simulations and are presented by each team at a formal briefing at the end of the semester. This formal briefing is open to the university and is scored by a panel consisting of faculty members and guests from industry.

In addition to the general requirements described above, students in the Aircraft Detail Design course have the option of pursuing a DBF design of a full aircraft model. The DBF teams still must focus on the structural design and test of a single aircraft component, but perform static structural testing to only 80% of design limit load rather than testing to failure (which is the requirement of non-DBF teams). Limiting the load applied during the test allows the component to be optionally used as a part of a flight test article later in the semester while still affording the team the opportunity to verify their ability to predict structural response via simulation. It should be noted that teams typically complete the incorporation of their structural test article into a flight test article, but this is not a requirement of the course for reason previously stated.

The chronology which led to the incorporation of the DBF option into the Aircraft Detail Design Course and the life lessons that resulted from this curricular change are discussed in the following paragraphs.

Chronology of the Aircraft Detail Design DBF Option

Prior to the curricular change, students in the Aircraft Detail Design course gathered data from wind tunnel testing that failed to correlate well with theoretical predictions. In addition, students generated structural analysis results using computer simulation (Finite Element Analysis) tools, but had no feel for whether or not the results made sense.

In the Fall 2003 semester, an instructor change in the Aircraft Detail Design course led to a major curriculum alteration that emphasized component design and the addition of structural testing of scaled models of aircraft components. The new curriculum required student teams to build both wind tunnel and structural models of an aircraft component (e.g., a wing section, tail section, pylon) to allow students an opportunity to verify both aerodynamic and structural analysis methods.

Therefore, beginning in the Fall 2003 semester, students were required to select a single component from the aircraft they developed in the Preliminary Design course and concentrate on the design of that component alone. They were first required to fabricate and test a wind tunnel model of the selected component, with the intent of determining coefficient data that would allow verification of the aerodynamic coefficients derived during the preliminary design process.

The students then used the coefficient data to verify loads predictions for the component being designed. Concurrently, students designed a scaled structural model of their chosen component to sustain critical design loads (verified by the wind tunnel results). Since the structural model was scaled, an emphasis was placed on verification of analytical method versus design of the full-scale component. Students were required to simulate their structural model as it was actually built and constrained using a Finite Element Model, and then verify their ability to predict structural response by comparing strain and deflection measurements obtained from the actual model to those predicted by the computer simulation.

In Spring 2006, the course took a different path when the DBF option was introduced. This option was initiated to allow the development of a vehicle capable of being launched using a mag-lev rail system designed and fabricated as a part of a NASA grant program. Brainstorming led to the idea of having two (2) design teams create competing designs as a part of the Preliminary Design course. Since it was assumed that taking on the additional tasking that would be required to design and build a full aircraft flight test article would require additional manpower than that of a typical Detail Design team, it was decided to have the two teams combine into one ‘super team’ in the Detail Design course. Since wind tunnel testing was already an important component of the detail design process, it became immediately apparent that wind tunnel testing was the most logical means for deciding which of the two competing designs would have the most promise as a flight test article. This down select process would need to be completed during the first five to six weeks of the semester to allow the combined team sufficient time to complete the design, build, and flight test of the selected concept. It should be noted that it was necessary to continue to require structural testing of a selected component (typically a wing) as a course goal for the DBF team to maintain similar course outcomes to those Detail Design teams which choose to pursue non-DBF designs. This structural test requirement made the flight portion of the design purely optional, with the potential of ‘bonus’ grade points being part of the incentive provided to students to complete the flight test.

This DBF option is now engrained into the Preliminary Design course where two (2) design teams are provided identical RFP’s in the form of a design competition which culminates in the Detail Design course as a wind tunnel ‘fly-off’. The two Preliminary Design teams combine to form a single team of 12-16 students in Detail Design. The two former teams become ‘design groups’ which continue to develop their designs through the fabrication of full aircraft wind tunnel models making use of rapid prototyping wherever possible.[1] The models are then tested using identical procedures and the results are submitted to a faculty panel which then selects the design which appears to have the most promise as a flight test article. Teams which choose this DBF option still have the requirement to perform structural tests to verify a finite element simulation; however unlike the non-DBF teams in the Detail Design class they do not test to failure. The DBF teams instead perform a ‘proof’ test to 80% of the predicted limit load so that their component can be used for their flight test article. The DBF team is then allowed to pursue the design and fabrication of a flight capable vehicle.

It is important to note that every component included in the flight test article must be verified analytically and documented via a ‘pre-released’ drawing package prior to component fabrication. A radio controlled (RC) flight control system is then incorporated into the design to allow for a remotely piloted flight test operation. The team is required to prepare a formal flight test plan including a 'go/no-go' list similar to what would be used for a UAV flight test in industry.

This DBF competition is unique in that it involves competing designs being devised by teams within the same course at the same school. Typically, DBF competitions pit aircraft designs fabricated by teams representing an entire campus or university against those from other schools. A well known example of this is the annual American Institute of Aeronautics and Astronautics (AIAA) DBF completion which is held every Spring. While these competitions provide students with an opportunity to gain valuable experience working within design teams, they do not allow students the opportunity to learn the life lessons inherent in the ERAU capstone model.

Although the DBF option is considered an excellent learning experience, not all students wish to pursue the somewhat simpler designs required for the successful completion of the DBF project. Students who are interested in high speed jet aircraft design, for instance, can choose to complete the preliminary design of an advanced fighter aircraft, knowing that they will turn their attention to wind tunnel testing of their design and the structural test of a single aircraft component in detail design. These students also get excellent design experience, which is the ultimate desired outcome of the course. The university is also limited to pursuing only one DBF option per semester due to the additional costs incurred for full aircraft fabrication, which requires one or two design teams to pursue non-DBF options due to cost constraints.

The following section provides an illustrated chronology of a recent DBF design project.

Illustrated Chronology of the DBF Design Process

The following figures provide an illustrated chronology of the DBF designs which competed during the Spring 2009 semester. Figure 1, below, shows the CAD renderings of each design, as completed during the preliminary design phase.

Figure 1 – CAD Renderings

The Spring 2009 competition involved reconnaissance UAV designs, with 12 foot wingspans for the flight test articles, as depicted in Figure 1.

Each design group fabricated scaled wind tunnel test models for data collection and flow visualization, as shown in Figures 2 and 3, below.

Figure 2 – Wind Tunnel Models

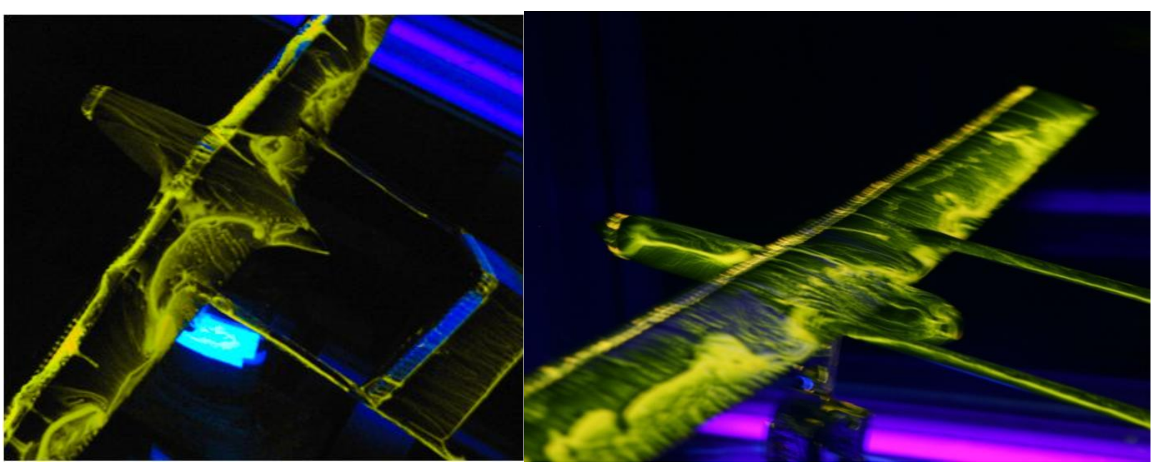

Figure 3 – Flow Visualization

These figures show the scaled models being tested in the ERAU, Prescott low-speed wind tunnel. The resulats obtained from wind tunnel testing were used to down-select to the concept on the right which was then structurally tested and flight tested.

Figure 4, below, shows the structural test of the selected concept.

Figure 4 – Structural Proof Test

The figure shows sandbags being applied to the underside of the wing surface to simulate lift on the inverted test article. Only 80% of the design limit load is applied to preclude structural failure which would prevent the use of the wing structure for the flight test article. Strain and displacement measurements are recorded for ten (10) load steps, with the results compared to a finite element simulation. This simulation attempts to model the lift distribution and mechanical contraints as they are applied to the test article.

The last step in the process is flght test. Figure 5, below, shows the flight test article on the runway prior to the aircraft’s first taxi test..

Figure 5 – Flight Test Article

Figure 5 also shows the team and both instructors enjoying this proud moment. It should be noted that half of those present represented the design group which spent four acedemic months designing the concept which was not selected.

The DBF option has been pursued on five occasions since the Spring 2006 semester, with varying levels of success. What has been constant, however, is the exposure that students receive to life lessons in terms of collaboration with a former competitor and the feeling of loss that one design group is forced to experience when one of the concepts is 'left behind'. The following section addresses these experiences and their impact on student learning.

Life Lessons Resulting from the DBF Option

The DBF option documented in the preceding section was aimed at enhancing student preparation for their professional lives. This preparation is a critical student outcome of engineering capstone courses and can be established in a number of effective ways:

- By having students work within multi-disciplinary design teams.[2]
- By providing instruction geared toward oral and written communication skills.[3,4]
- By focusing on the ethical foundation of the engineering profession.[4]
- By teaching social awareness through interaction with real-life customers.[5]

While the ERAU aircraft capstone sequence incorporates the first three of these attributes, it is unique in that it provides the additional components of induced collaboration with a team of students which may have been previously seen as adversarial, and the introduction of the potential for loss in terms of a project down-select. These components allow students to experience what many engineers in industry have experienced as a result of company mergers or being on the losing end of a design competition. Although these life lessons result in team conflicts and anger over having to leave a substantial investment in time and energy behind, the feedback received from students regarding this course methodology has been overwhelmingly positive (as further discussed in the following section).

The preparation for this process begins while students are still enrolled in the Aircraft Preliminary Design course. The Detail Design instructor delivers two guest lectures to the Preliminary Design students to inform them of the process that will occur as they transition to the Detail Design course. These lectures lay the groundwork for the two independent teams combining into a single entity with the end goal of designing and manufacturing a flight test article representative of the more promising of the two designs. The students understand that it is to their benefit to put in an optimal effort in the wind tunnel testing portion of the Detail Design course in order to achieve the most representative results possible. The teams also know that one of their designs will not be moving forward to the production phase, and that it behooves them to become more knowledgeable of their competitor's design should that design be chosen over their own.

The first class period of Detail Design is dedicated to providing teams with Statement of Work documents which clearly provide the two previous competing teams with tasking which will require the two design groups to work together as a single team toward a common goal. The two teams sit down together and formulate a schedule and a distribution of tasks such that each team member is given the opportunity to work in their areas of interest. The instructor encourages at least one design group member to volunteer to work on the opposite group's wind tunnel model construction to gain a better understanding of the intricacies of the design and encourage team collaboration.

The team continues to work as two design groups for the first five weeks of the semester until wind tunnel testing is complete. However, weekly team meetings including both design groups are required, and the team is encouraged to refer to themselves as a single unit, rather than 'us' and 'them'. After the wind tunnel test results are evaluated by a faculty panel, one of the two designs is chosen leading to another life lesson, that of loss.

The emotions that students display immediately after the down-select typically include anger and resentment (along with joy for the design group responsible for the selected design). These emotions have been voiced during student-instructor meetings and in the course evaluations compiled at the end of the semester. This loss represents a major academic set-back in the minds of many of the students, and thus the 'healing' time varies depending on each student's maturity. It must be remembered that the students have devoted hundreds of hours outside of the classroom over four months of their academic lives to their designs by the time the down-select occurs, so naturally the pain of loss can be quite intense. However, this feeling typically subsides as both design groups focus on the task of designing, fabricating, and testing an aircraft structure and control system within a two-month window. The excitement of designing an actual aircraft with the potential of flight test often lessens the pain of loss even if the aircraft represents the design of their previous competitor. The course instructors also devote considerable time to address any continued resentment through conflict-resolution planning and individual student meetings.

Evaluation of Success

Although a quantitative assessment of the success of the capstone curriculum change is difficult at this time due to sparse data, a qualitative appraisal is possible based upon student course evaluations, senior exit interviews, and feedback received from alumni.

The percentage of positive student comments relative to the processes utilized as a part of the DBF option has been overwhelmingly positive since the DBF curriculum change was introduced in Spring 2006. Overall, students greatly appreciate the opportunity to apply real-world based design methods and verify their results through wind tunnel and structural testing, followed by the true test of their designs: flight test. Seniors have also voiced their overwhelming approval of the learning environment present in the Aircraft Detail Design course in senior exit interviews documented since the curriculum change. These responses indicate a continued satisfaction with the course requirements, even though they have become much more demanding with the inclusion of the DBF option, as evidenced by the increased number of hours invested per team per semester. The interview results indicate that, in general, students understand that the uncomfortable situations introduced through forced collaboration and loss are worthwhile in terms of their educational value. A typical student comment which follows this theme is: "The detail design course requires the DBF team to be physically and emotionally challenged, yet provides a complete capstone experience. This course proved to me that life is not always an enjoyable ride and I applaud the instructors for preparing us so well to go into industry."

Ideally, alumni surveys would be evaluated to determine whether the change in curriculum had enhanced ERAU graduates' abilities to immediately apply what they have learned and better prepared them for similar experiences in industry. However, because the curricular change has only recently been implemented, the surveys provided to recent ERAU graduates do not include questions which would allow evaluation specific to the changes resulting from the DBF option. Nevertheless, multiple alumni have sent email messages fully endorsing the DBF option and suggesting that it has left them better prepared for the transition to the demands of industry.

Enhancement of ABET Outcomes

The ERAU AE capstone sequences allow students to meet the majority of the ABET required outcomes (identified as (a) through (k) as defined by ABET Criterion 3), specifically:

- (b) an ability to design and conduct experiments, as well as to analyze and interpret data;
- (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
- (d) an ability to function on multi-disciplinary teams;
- (e) an ability to identify, formulate, and solve engineering problems;
- (f) an understanding of professional and ethical responsibility;
- (g) an ability to communicate effectively;
- (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context; and
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The DBF option specifically addresses the social constraints identified by outcome c) by forcing students to overcome potential barriers in terms of collaboration and competition. It also could potentially address outcome h) in terms of a broad education in a societal context in that it places students in situations that will allow them to better interact with fellow engineers and face societal issues more confidently due to the life lessons learned in the class.

Application of Acquired Knowledge and Program Enhancement

Over the five semesters that the DBF option has been offered, several improvements have been identified which have and will be applied to future DBF projects. The first is the necessity of acquiring verifiable data upon which to base the design down-select. In the past, questionable data achieved from the wind tunnel testing has been used to justify the elimination of one of the two design options, using the need for a timely selection as the basis for this decision. However, due to the tremendous effort put forward by the design groups prior to the down-select, hasty decision-making has resulted in high levels of resentment toward faculty and the students comprising the winning team. Therefore, additional investment has been made in acquiring wind tunnel equipment which has a proven level of accuracy necessary to provide reliable results upon which the down-select decision can be made.

A second improvement is in regards to limiting the scope of the project to allow students to complete a flight test article that has a reasonable chance for success. RFP's have been offered to students as a part of the DBF option which were too advanced to allow students to complete the design and fabrication of a flight test article in the allotted time frame. Therefore, RFP's are now being limited to more reasonable requirements to provide students with a higher probability of success, thereby limiting the frustration caused by incomplete projects.

Finally, follow-up alumni surveys are being planned to acquire quantitative data specific to the DBF option which will be used to assess the success of this curricular modification. These surveys will also be used to identify additional tools that could be incorporated into future DBF programs to better prepare AE graduates for professional challenges.

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Spaghetti Bridges: Build, Load and Repeat

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Abstract

The construction and subsequent loading of a bridge made out of spaghetti has proven to be an effective instructional tool in combining elements of materials science, mechanics (statics) and manufacturing. This paper reports the advantages of requiring the students to repeat their design layout with slightly different manufacturing criteria instead of just completing one design. The use of spaghetti bridges in introduction to engineering courses has been done before; however, only one bridge is typically done per student team. Requiring the students to design more than one bridge and loading each to failure has a greater impact on student learning by forcing the students to understand the consequences of the differences between their bridges. A description of the design project and the results from implementing the project in improving the impact on student learning and the appreciation of engineering are reported.

Introduction

The construction and subsequent loading to failure of a spaghetti bridge is detailed in Karweit[1]. In this seminal work, the benefit of a "virtual lab" (www.jhu.edu\virtlab\bridge\truss.htm)[2] was used to dramatically improve the overall performance of the final designs, at least in two dimensional space, i.e. the maximum capacity was significantly increased by conducting virtual loading of the design.

Construction is a critical component of these spaghetti bridge projects. Construction clearly demonstrates the third dimension pitfalls[1]. The bridge design criterion is detailed in the Materials and Methods section below. The use of spaghetti bridges in introduction to engineering courses has been done before; however, only one bridge is typically done per student team[3]. Construction of these bridges is labor-intensive, and as a result, rarely are prototypes constructed and tested. However, if the three to four person teams work efficiently, at least two full scale bridges can be constructed in an appropriate predetermined timeframe (typically five hours per bridge).

This paper will focus on the advantages of having the students repeat their design layout with slightly different manufacturing criteria versus just completing one design. As a result, each team will test two bridges to failure. A description of the design project and the results from implementing the project in improving the impact on student learning and the appreciation of engineering are reported.

Materials and Methods

Project Description:

Each team is to build two bridges made solely from spaghetti and epoxy. The objective is to construct a design that will carry the heaviest load while meeting the specifications summarized on the following page. Completed bridges are loaded until failure.

Rules and Specifications:

1. The bridge is to be built solely from spaghetti and five minute epoxy. Per three or four person team, the two bridges are to be as identical as possible with the ONLY exception being that one bridge can have epoxy at any location and <u>the other bridge can only have epoxy up to 1.5 cm in any direction from the node</u>. Disqualification will result if this is violated.
2. The bridge shall be free-standing and must span two level surfaces which are one-half meter (50 cm) apart (Figure 1).
3. Support for the bridge shall be from the *top* of the level surfaces only. The *edges* of the level surfaces cannot be used in any way for support.
4. The bridge must include a decking of spaghetti to provide a suitable "road surface" at least 5 cm wide across the full span of the bridge. Three conditions must be met:
   a) gaps in the bridge deck are not to exceed 2 mm.
   b) a block of wood (5 cm x 5 cm x 10 cm), representing a car, must be able to move the entire length of the span unobstructed.
   c) the deck of the bridge must not be more than 5 cm above or below the ends of the bridge at any point along its length.
5. A "loading platform" consists of a piece of plywood (.7 cm x 5 cm x 10 cm) and an eye-bolt. This platform is to be attached at the center of the bridge such that the bottom of the eye-bolt is no more than 5 cm from the top of the bridge decking. All loads will be suspended from this eye-bolt, and there must be a clear space directly below the eye-bolt to allow loads to be attached. Loads will be attached using an S-hook (Figure 1).
6. The maximum vertical height of the bridge cannot exceed 25 cm.
7. The maximum mass of the bridge including the loading platform cannot exceed 200 grams (Figure 2).

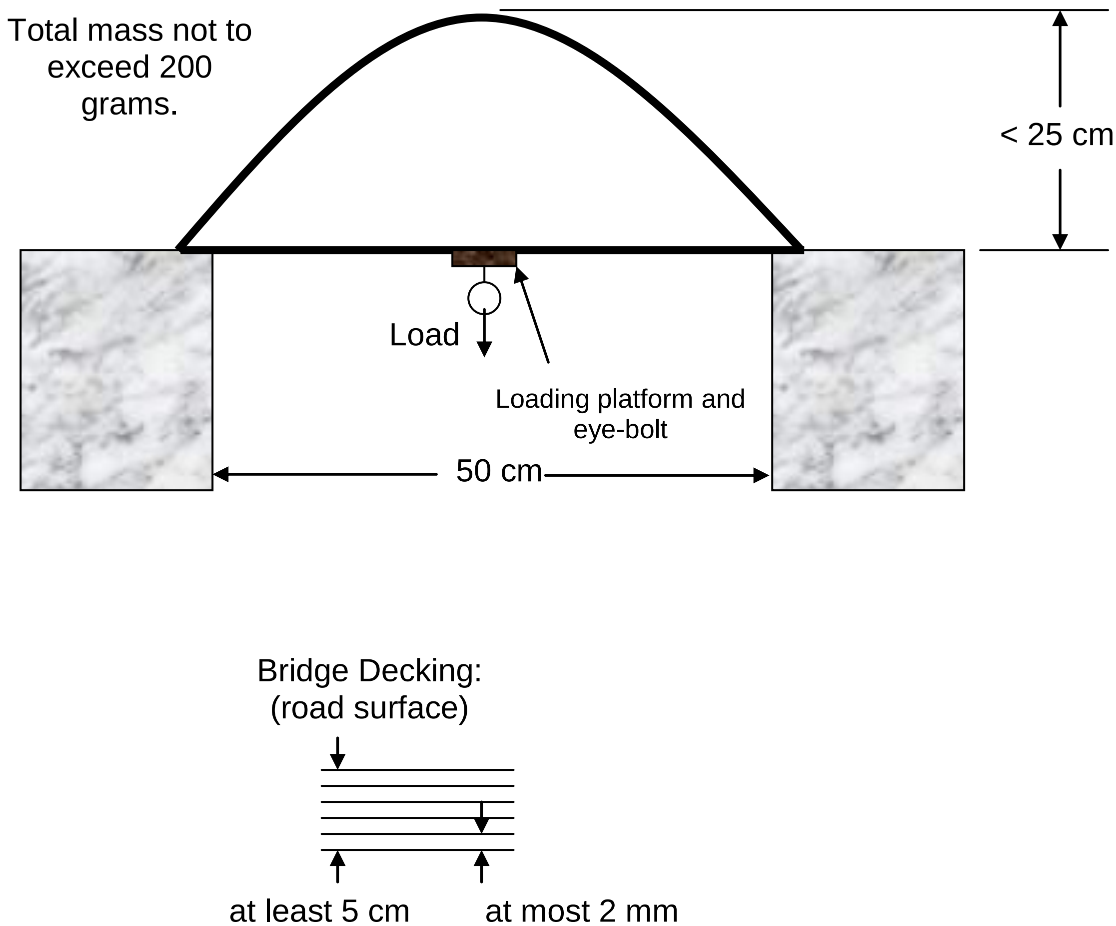

Figure 1: Bridge specifications. Note: not drawn to scale

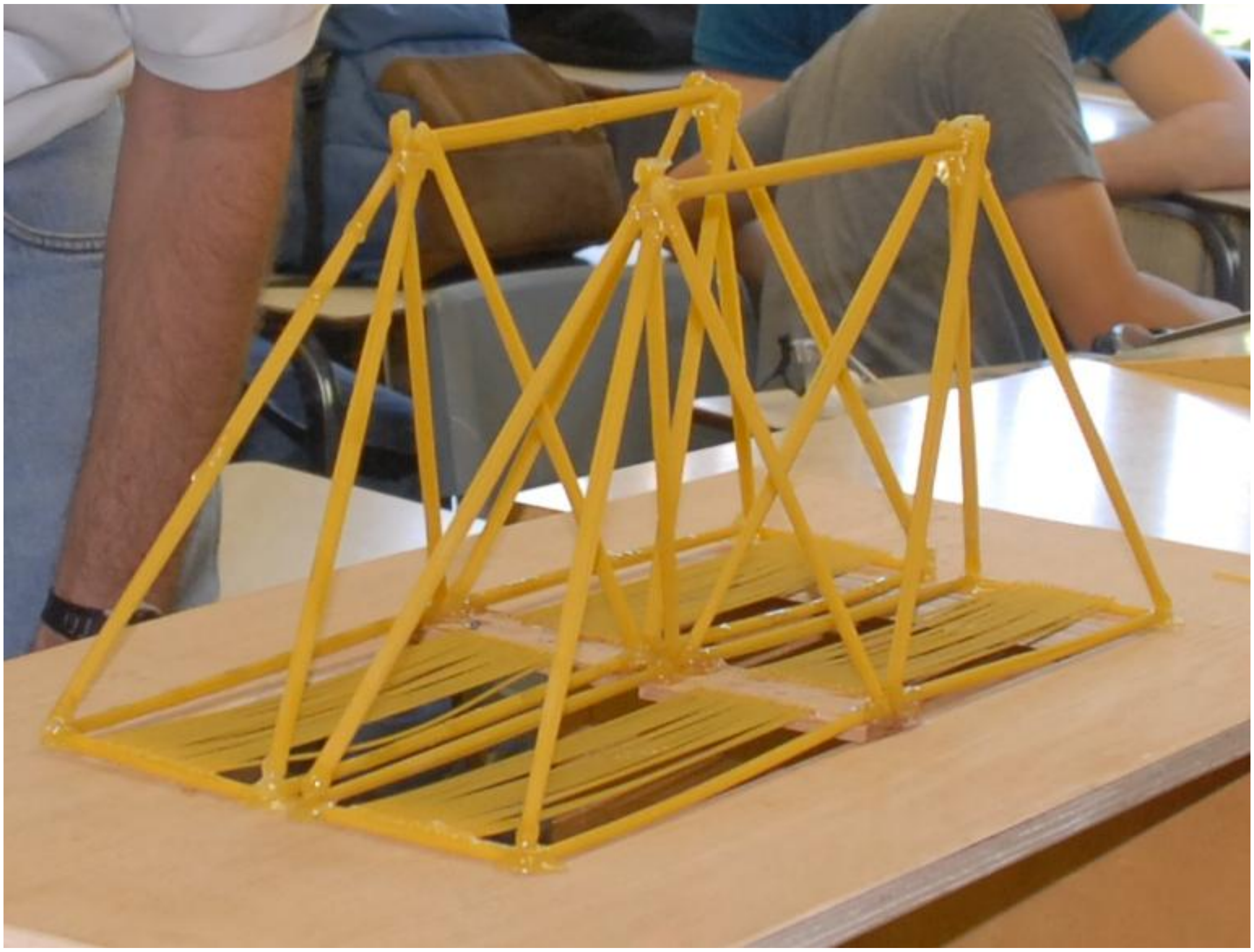

Figure 2: Spaghetti bridge testing.

Results and Discussion

Three or four person student teams were tasked with building two bridges using the criteria previously described. This preliminary study is summarized in Table 1: the load to failure for eight undergraduate teams in a second year materials science class. The "1.5 cm Epoxy Bridge" column refers to the bridge that only had epoxy up to 1.5 cm in any direction from a node. The "Unlimited Epoxy Bridge" permitted a liberal use of epoxy, but all bridges had to be less than or equal to 200 g.

Table 1: Load capacity per team for each bridge.

Team	1.5 cm Epoxy Bridge Load [kg]	Unlimited Epoxy Bridge Load [kg]
A	5	10
B	3	10
C	4	7.5
D	2	4.5
E	4	3
F	3	2
G	2	2
H	2	2

The liberal use of epoxy produced stronger bridges (e.g., teams A-D). However, when the design was fundamentally flawed as in teams E-H, an increase in load was not achieved and indeed the loads appear to plateau at a two kilogram load. This plateau which indicates little, if any, improvement in load capacity with added epoxy justifies the effort of manufacturing two bridges by serving as a learning tool for the students.

With only one bridge required in previous attempts at this project, teams would often dismiss poor performance as either a material and/or manufacturing defect. Their body language often suggested that their design would have been just fine if it were not for errors that could be fixed with improved materials and/or manufacturing skills. For teams E-H in Table 1, the data suggests that they had two attempts to improve their manufacturing skills, and despite the composite nature of a liberal use of epoxy, their bridge design did not perform well. In contrast, teams A-D in Table 1 increased their load capacity with epoxy/spaghetti composite thereby validating their design, and in the process serving as a means of emphasizing the difference in the material properties of spaghetti and epoxy.

From the instructors' perspective, there is always that fine line as to how much assistance one should provide. When an excessive amount of spaghetti and epoxy are devoted to the horizontal "road surface," one can only ask the students how much load that portion of the bridge can possibly carry? In point of fact, if the students do not recognize that the roadway surface is not the best use of material, the actual loading of their bridge definitely highlights this point. The authors feel this is a valuable lesson to learn and witness by loading their bridges to catastrophic failure.

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A Laboratory-Based Course in Aerospace Engineering Failure

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Abstract

This paper reports on a unique laboratory-based course in aerospace engineering failure created for undergraduate engineering students. The three-credit hour course is intended as an upper-level technical elective for students in the Aerospace and Mechanical Engineering Department at Embry-Riddle Aeronautical University at the Prescott, Arizona campus. The lecture is held twice a week and the two hour and forty minute laboratory is conducted once each week. The emphasis is on structural and materials failure mechanisms, tailored with an emphasis on the aerospace industry. The course is composed of a set of learning modules, and includes advanced fatigue and fracture, thermo-mechanical failure, fastener failure, wear, corrosion, impact of composite materials, statistical analysis of failures, non-destructive evaluation (NDE), and structural health monitoring. Typically, these topics are not presented in most undergraduate engineering degree programs. The course has significant "hands-on" learning, and students use equipment such as the scanning electron microscope, hydraulic load frames, and damage detection equipment which are not offered for undergraduate use in most engineering programs. A significant amount of new learning materials has been created and are being made available to the public online, and a select portion of the laboratory component will be assembled into a module to be presented to high school students at the yearly Aerospace Engineering Summer Camp held at Embry-Riddle.

Introduction

The Aerospace and Mechanical Engineering undergraduate degree programs at Embry-Riddle Aeronautical University (ERAU) in Prescott, Arizona, are four-year undergraduate engineering degree programs. There are close to five hundred students in these two degree programs, most of which are in AE. There are no engineering graduate students at the Prescott campus. The Aerospace Engineering (AE) degree program is ABET accredited, and the Mechanical Engineering (ME) degree program, which is new on the Prescott campus, will undergo its first ABET accreditation visit during the summer of 2010.

The Prescott campus of ERAU might be thought of as a "teaching institution," where emphasis in the undergraduate engineering programs is placed on faculty-student interaction, design experiences, and hands-on laboratory learning. Design projects are sprinkled throughout the curriculum starting from the freshman year[1], culminating in a significant and intensive two-semester design, manufacturing, and testing sequence during the senior year[2]. Many of these design experiences require students to spend considerable time in the machine and fabrication shop constructing test articles and additional time in the laboratory completing testing. Aerospace engineering students specialize in either aircraft design or spacecraft design. The recently formed ME degree program is also tailored to have an aerospace flavor, and the senior design specializations are air-breathing propulsion and robotics.

A 20,000 square foot manufacturing and laboratory facility was completed and opened in May 2006[3], and is dedicated solely to the AE and ME degree programs. This facility more than doubles the existing manufacturing and laboratory space for these degree programs, and is both a campus showpiece and a critical tool for implementing the kind of hands-on instruction important to ERAU. In this facility, students have access to equipment not normally available to undergraduate engineering students at most universities; the use of this equipment is regularly incorporated into the engineering curriculum at ERAU. Features include a machine shop with adjoining light fabrication spaces (the latter for after-hours work), rapid prototyping capabilities, an astronautics lab with shaker tables and vacuum chambers and an air bearing, several load frames as well as a large reaction frame for structural testing, and a materials science and microscopy suite. Students are expected to become reasonably competent at operating certain laboratory equipment, such as wind tunnels, load frames, and scanning electron microscopes (SEM), to which they would receive minimal exposure at many other universities, and this makes Embry-Riddle unique in this regard.

Within this context, the authors wrote a successful proposal to the National Science Foundation (NSF) to fund the creation of a laboratory-based course on materials and structural failure. The emphasis is on failure modes and related issues that especially pertain to the aerospace industry, primarily because of the overall emphasis on the aerospace industry generated at Embry-Riddle Aeronautical University. The course syllabus is influenced by the technical skills and knowledge of two of the primary authors, Lanning and Lestari.

Course in engineering failure

The name of the new course is *Aerospace Engineering Failure*. The three-credit hour course is an upper-level technical elective for undergraduate students in the Aerospace and Mechanical Engineering Department in the College of Engineering at the Prescott campus of ERAU. The lecture is held twice a week (two credit hours) and the laboratory is conducted once each week for two hours and forty minutes (one credit hour). The prerequisite course for the proposed *Aerospace Engineering Failure* course is the junior level Aircraft Structures I, from which students are expected to have a knowledge of basic fatigue and fracture concepts, stress and strain failure criteria, and finite elements. While it would be desirable, the Engineering Materials Science with Laboratory that is required of both AE and ME students is not a prerequisite. A fair number of students put off this engineering materials course until their very last semester or two, unfortunately. Therefore, to allow for adequate enrollment in this new elective course, prerequisites must be kept to a minimum.

Students receive separate grades for the lecture and laboratory portions of *Aerospace Engineering Failure*. The lecture grade consists of scores from homework, scheduled quizzes, one midterm, and a final exam. The laboratory grade is based upon assignments accompanying most laboratory topics, the presentation of a subset of laboratory results on the course webpage (to be made available to the general public at aerospacefailure.erau.edu), and the submission of an electronic portfolio of all laboratory work at the end of the semester.

The lecture is in large part meant to ready students for the laboratory sessions. The importance of laboratory work is critical to a proper study of engineering failure. Students are expected to understand proper testing procedures, such as found in the comprehensive ASTM International (originally American Society for Testing and Materials) standards, and to use state-of-the-art equipment to perform testing and post-failure analyses. Detailed laboratory methodology is required, such as taking dimensions, specimen surface preparation and cleaning, strain gage placement, test planning, and interpretation of results. Fracture surface evaluation for various modes of failure, using the scanning electron microscope (SEM), is emphasized in many of the laboratory sessions.

It should be noted that laboratory experiences are critical to achieving ABET accreditation, especially for the ABET plan as written by the engineering faculty at the Prescott campus of ERAU. However, since this course is not a required course, but an elective course, it can only serve in a supplementary way towards achieving ABET objectives and outcomes.

The course was first taught during the fall 2009 semester. The course will again be taught during the fall 2010 semester. It is intended that improvements and revisions to the course learning materials occur during the spring and summer of 2010, and that the course will be taught with some regularity thereafter.

Course content

A summary of each course module is provided here, by topic, in the intended sequence of presentation. Each module has a duration from one to two weeks. It is intended that the laboratory sessions quickly follow the appropriate lectures for continuity. There is no course text, since the authors know of no appropriate text that would satisfy most of the goals of this unique course. In fact, this was one of the arguments made by the authors in the proposal requesting NSF support, as an indication of the distinctiveness of this course within undergraduate course catalogs.

Introduction

An introduction includes an historical perspective of engineering failure, with an emphasis on the aerospace industry, including a survey of prominent failures and comparisons between fail-safe, safe-life, and damage tolerant design strategies. For the laboratory session, an introduction to failure surfaces is performed. A range of failure surfaces are rapidly produced through various loading modes, producing a range of failure surfaces. Macroscopic and microscopic preparation and characterization techniques, including the use of the scanning electron microscope (SEM), is practiced. Students develop a database of fracture surfaces, which is maintained throughout the semester.

Stress-life and strain-life fatigue analysis

Students will have had an approximate two-week introduction to fatigue and fracture mechanics during the prerequisite course, Aircraft Structures I. The aim of the first three weeks of *Aerospace Engineering Failure* is to provide advanced studies in fatigue and fracture mechanics. Stress-life methods are quickly reviewed here. Strain-life methods are usually not covered in the prerequisite course. Monotonic and cyclic stress-strain behavior are therefore discussed, including cyclic hardening and softening, mean stress effects, and the Coffin-Manson relationship[4,5]. The laboratory experiment is intended to consist of cycling cylindrical fatigue specimens (three or four during the course of the week) to failure with maximum stresses above yield, including the generation of hysteresis loops and fatigue parameters from several of the so-called power-laws used for common strain-life analysis. This laboratory session did not occur during fall 2009 semester due to some difficulties in manufacturing appropriate specimens, but will be strongly considered for inclusion when the course is again taught in the fall 2010 semester.

Notch fatigue

Notch analysis in fatigue is a one-hour lecture topic. Stress-life methods, fatigue notch factor, notch sensitivity, and notch size effect are covered. The use of finite element analysis (FEA) to solve certain problems is expected. The laboratory requires the students to stress-life test several notched flat fatigue specimens. The instructors previously tested baseline unnotched specimens of the same material prior to the start of the semester. The students use both data sets to perform a fatigue notch analysis. Students use the SEM to view fatigue striations and the overload region.

Crack growth

A quick review is provided of fracture mechanics concepts learned in the prerequisite course, such as stress intensity factor, fracture toughness, and the Paris equation. The use of common solutions for the stress intensity factor (center-cracked panel, semi-elliptical crack in a plate, etc.) is applied to monotonic and cyclic crack growth problems. The plastic zone size and effect on crack growth are also discussed. The second and third lectures include crack propagation from notches, crack closure concepts, the effect of overloads and underloads, and crack growth under variable amplitude loading. The laboratory requires students to perform crack growth tests with compact tension specimens. The required AE/ME course in Engineering Materials Science, which students may or may not have taken at the time they take *Aerospace Engineering Failure* , currently has a one-week laboratory on the use of direct current potential drop (DCPD) to perform basic crack growth analysis using the Paris equation for several compact-tension (CT) specimens cycled at constant-amplitude loading conditions. The laboratory session in this new course does not assume prior knowledge of crack growth testing. Baseline constant-amplitude crack growth data are be available from testing performed by the instructors prior to the beginning of the semester. The focus will be on crack growth rates influenced by periodic overloads, variable amplitude loading, or some other topic that goes beyond work done in the engineering materials course.

Thermo-mechanical failure

One week is spent on thermo-mechanical failure. The topic is introduced with material properties at elevated temperatures and thermal shock. Creep behavior, creep models, and general viscoelastic behavior is then presented. The laboratory session consists of elevated temperature testing, such as tension testing, relaxation (constant displacement) testing, or creep (constant load) testing. As usual, fracture surfaces are retained for microscopic examination.

Fastener failure

Figure 1. Students constructing fastener test specimens.

One week is spent on practical aspects of fastener failure. Fastener types, such as various rivets, bolts, and welds are discussed, along with typical failure modes (fastener shear, bearing, shear-out, bolt bending, pull-through, etc.), edge distance influence, improperly installed fasteners, and weld efficiency. Two laboratory sessions are required for manufacturing and testing fasteners. Students manufacture a number of specimens for subsequent testing (Figure 1). Strips of metal or composite material are fastened with various rivets and bolts for axial tension or fatigue testing. Additional variations, implemented on a student-by-student basis, include edge violations, over- and under-driving of rivets, the use of various rivet patterns, flat head versus counter-sunk rivets, and over- and under-tightening of bolts. Mechanical testing of the manufactured specimens is conducted during the second week of the fastener laboratory. Students document the mode of failure for each specimen, compare specimen strengths to predictions based upon both theory discussed in lecture and fastener strength data, and perform microscopy on a subset of the fracture surfaces.

Wear

One week is spent on a survey of wear damage. Included topics are various types of wear, fretting, rolling contact, erosion, and the effect of these on mechanical properties. No accompanying laboratory was conducted during the fall semester of 2009, but a future option is to devise a method for inducing a quantifiable amount of abrasive wear on standard dogbone specimens, test in either tension or fatigue, and compare to results from undamaged specimen testing.

Corrosion

One week is spent on failures due to corrosion. A quick summary of the various forms of corrosion (Fontana's eight forms of corrosion[6]) is provided. A subset of these forms of corrosion are discussed in depth: galvanic corrosion, stress corrosion cracking, and hydrogen embrittlement. An experiment on stress corrosion cracking of aluminum alloys following the guidelines from ASTM G47[7] is performed. A student was hired to build a device for alternately soaking and drying the pre-strained specimens (a motorized Ferris-wheel, Figure 2), and ended up building a beautiful fully-functioning test apparatus. Corroded specimens are subsequently failed in tension and fatigue, and predominately compared to uncorroded specimens through examination of the fracture surfaces.

Figure 2. Device for alternating soaking and drying of corrosion test specimens.

Impact and composites damage

One week is spent on impact damage and damage to composite materials, including high strain rate loading, impact energy, foreign object damage (FOD), and the various failure modes seen in a variety of impacted composite materials (matrix cracking, fiber pull-out, delamination, and debonding). The Charpy impact test is mentioned only briefly, since this is a standard topic and laboratory exercise in the required Engineering Materials Science course. Students build several panels from pre-impregnated glass and carbon composite sheets, cure the panels under vacuum bagging in an oven, and then used a simple impactor device to create damage. These damaged plates are then used in a health monitoring experiment (discussed subsequently). The student assistant who built the corrosion device mentioned above has drawn up plans for a drop tower for measured impacting of specimens, to be built prior to the beginning of the fall 2010 semester.

Statistics for failure

Several lectures are spent on the use of statistics for failure analyses. Topics include the use of statistical distributions to model failure data and elementary reliability theory. Example problems with small and large data sets are presented. A one-week laboratory experiment generating a significant amount of failure data is conducted. The fall 2009 semester experiment was the three-point bend testing of glass microscope slides, which could be accomplished numerous times rapidly, generating a data set that can be successfully modeled by various distribution functions and reliability theories.

Nondestructive evaluation

Students are given a one-week introduction to non-destructive evaluation (NDE) techniques, in which several available technologies to identify failure in aircraft structures are discussed. Conventional and advanced NDE technology includes visual inspection, liquid penetrant, magnetic particle inspection, eddy current, ultrasonic, acoustic emission, shearography, and laser ultrasonic methods. The laboratory consists of demonstrations of selected NDE techniques, i.e. liquid penetrant, magnetic particle inspection, eddy current, and ultrasonic, conducted on several metallic test samples with introduced flaws.

Structural health monitoring and aging aircraft

The lectures on NDE serve as a segue for discussions on aging aircraft and structural health monitoring (SHM) issues. The course material is comprised of basic theory and general concepts of SHM methods and an introduction of maintenance concepts for both aging and current aircraft. The students are introduced to a broad range of SHM techniques, e.g. vibration based, wave propagation based, acoustic based, and impedance based, as well as several sensor and actuator technologies. The course materials necessarily must remain simplified for undergraduate engineering students, who in particular may not have been yet exposed to many of the background prerequisite concepts. A one week laboratory on the demonstration of vibration-based SHM technique is conducted using the impacted composite specimens from the earlier laboratory on composite materials failure.

Evaluation

The evaluator for the project is Dr. Shirley Waterhouse, University Director of the Centers for Teaching and Learning Excellence, Office of the Provost, Embry-Riddle Aeronautical University. The Office of the Provost is based on the Daytona Beach campus, the sister campus to the ERAU Prescott residential campus. She has been leading the evaluation through monitoring the preparation of learning materials as well as the preparation of assessment tools, conducting faculty interviews, and leading a student focus group at the end of course implementation. The overall project goal is to monitor the development, and thereafter the adequacy and effectiveness, of new teaching and learning materials developed for *Aerospace Engineering Failure*. The evaluation also pays attention to the use of the laboratory environment to teach and reinforce failure concepts in structural and materials engineering. The evaluation has the following objectives:

1. Monitor the development of the course materials prior to course implementation and develop course evaluation tools
2. Document instructor and student satisfaction with course materials and student achievement
3. Document the positive, as well as negative, effects of learning materials on student learning outcomes
4. Examine the effect of the use of laboratory-based failure modules on reinforcing failure concepts

Details of the timeline for the proposed activities are provided in Table 2. Dates correspond to spring, summer, and autumn semesters at ERAU. A concept inventory exam will be created and used during the fall 2010 semester as part of the overall evaluation.

Evaluations are very positive to date, and suggest that the enrolled students were quite satisfied with the new course, especially with the ability to perform new and unique laboratory work. The instructors for the course (Lanning and Lestari) indicated that they believe preparations were generally successful, and they reported end-of-semester general satisfaction with the way the course has been proceeding. The instructors noted that there is room for improvement with some of the learning materials, to be expected with any new course, and this will occur during the second year of the project in anticipation of teaching the elective course a second time during the fall 2010 semester. The results of the final evaluation, the on-site focus group with enrolled students, will be made available to the instructors after final grades have been submitted for the semester and the Evaluator has written the final evaluation report for the first year (February 2010).

Table 1: Evaluation timeline

Dates	Activity	Participants
Summer 2009	Monitoring and evaluation of preparation of new learning materials and learning assessments	PI, Co-PI, Evaluator, and one student assistant
Week of Sept. 22, 2009	Student survey - evaluation of learning materials, course monitoring	Evaluator and enrolled students
	Instructor survey - evaluation of learning materials, course monitoring	Evaluator , PI and Co-PI
Week of Oct. 21, 2009	Student survey - evaluation of learning materials, course monitoring	Evaluator and enrolled students
	Instructor survey - evaluation of learning materials, course monitoring	Evaluator , PI and Co-PI
December 2, 2009	On-site focus group discussion with enrolled students	Evaluator and enrolled students
February 2010	Final report from Evaluator	Evaluator , PI and Co-PI
Spring to Summer 2010	Creation of concept inventory exam	PI and Co-PI
Fall 2010	Administer concept inventory exam	PI and Co-PI

Future work and summary

Select portions of the laboratory component are being assembled into a module on engineering failure for the yearly Aerospace Engineering Summer Camp held at Embry-Riddle, which exposes high school students to advanced laboratory equipment and creates excitement and interest in science, technology, engineering, and mathematics (STEM) disciplines. This will be first conducted in June 2010.

The challenges associated with this new course are much the same as the challenges of any new course, although the focus on strong student participation in the laboratory environment necessarily leads to an increased workload in preparation for the new and unique laboratory experiments and exercises. The enrollment of this course ended up at eight students during the fall 2009 semester, which was below the expectations of the instructors. However, the students enrolled were almost all quite strong students, and the smaller enrollment allowed for close guidance throughout the course. Also, this allowed for more flexibility during the laboratory sessions when various tasks took longer than expected.

Aerospace Engineering Failure will be taught again during the fall semester of 2010, and it is hoped that it will thereafter be taught at regular intervals and eventually incorporated into the ERAU Prescott campus academic catalog as a permanent addition to the technical electives offered in the AE and ME degree programs. The course website, which at this time primarily consists of selected student results from the laboratory, will eventually contain a full range of learning materials developed during this project.

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Low-Cost Take-Home Experiment on Classical Control Using Matlab/Simulink Real-Time Windows Target

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Abstract

This paper presents a low-cost hands-on experiment for a classical undergraduate controls course offered on behalf of non-electrical engineering majors. The setup consists of a small DC electrical motor attached to one of the ends of a light rod. The motor drives a 2-in propeller and allows the rod to swing. Angular position is measured by a potentiometer attached to the pivot point. A custom designed circuit board produces the controlled voltage input to the motor. The board communicates with the PC through its serial port using RS-232 protocol. A simple Matlab/Simulink module has been created to read the angle and send command signal to the motor. The module is based on Real-time Windows Target software allowing a sampling rate of 200Hz. Students are able to construct classical PID and phase lead-lag controllers, as well as modern controllers including state-space controller design and feedback linearization. The project was tested in a classical control systems design class offered to senior-level mechanical engineering students. Student feedback and survey data on the effectiveness of the module is also presented.

I. Introduction

Hands-on laboratories have been an integral part of the engineering curriculum since its inception[1]. Their importance has been recognized by the Accreditation Board of Engineering Education (ABET) and its predecessors by creating criteria requiring adequate laboratory practice for students[2-6]. During the last three decades, engineering laboratories have become more complex, including simulation tools and computer-controlled test and measurement equipment[7-8]. This increased sophistication has also led to more expensive equipment. The inclusion of such laboratory courses in the undergraduate curriculum is challenging due to the large number of students and the increased demand for instruction and equipment time. Hands-on experience, on the other hand, is invaluable for active and sensory learning styles, which are the predominant types of learning styles used by undergraduate students[9]. This paper describes the development and testing of a new low-cost take-home laboratory module designed to supplement the experience of our students taking their first course in Controls System Design. This project was developed primarily for students who are not electrical engineering majors, as these students typically do not have the benefits of electronic circuits training and tend to shy away from projects involving electronics. In the Aerospace and Mechanical Engineering Department of The University of Arizona, it is not unusual for the Control System Design course to have enrollment of about 100 students. This makes offering a laboratory section within the course nearly impossible. The project described here was developed primarily as a way to provide some practical experience to the students using an inexpensive and portable setup which can be taken home. The portability and low-cost of the setup allows them to conduct experiments during the semester and use the device to complete a term project. In addition to significantly reducing the cost of offering an experimental component, the experimental module provided an opportunity to demonstrate a modern approach towards control systems based on computers (digital control).

II. Experimental setup description

The setup consists of a small DC electric motor driven by a 5 V pulse-width modulated (PWM) signal. The motor is attached to the free end of a light carbon rod, while the other end of the rod is connected to the shaft of a low-friction potentiometer. The potentiometer is fixed on a plastic stand at the proper height, so that the pendulum can swing freely (see Fig. 1).

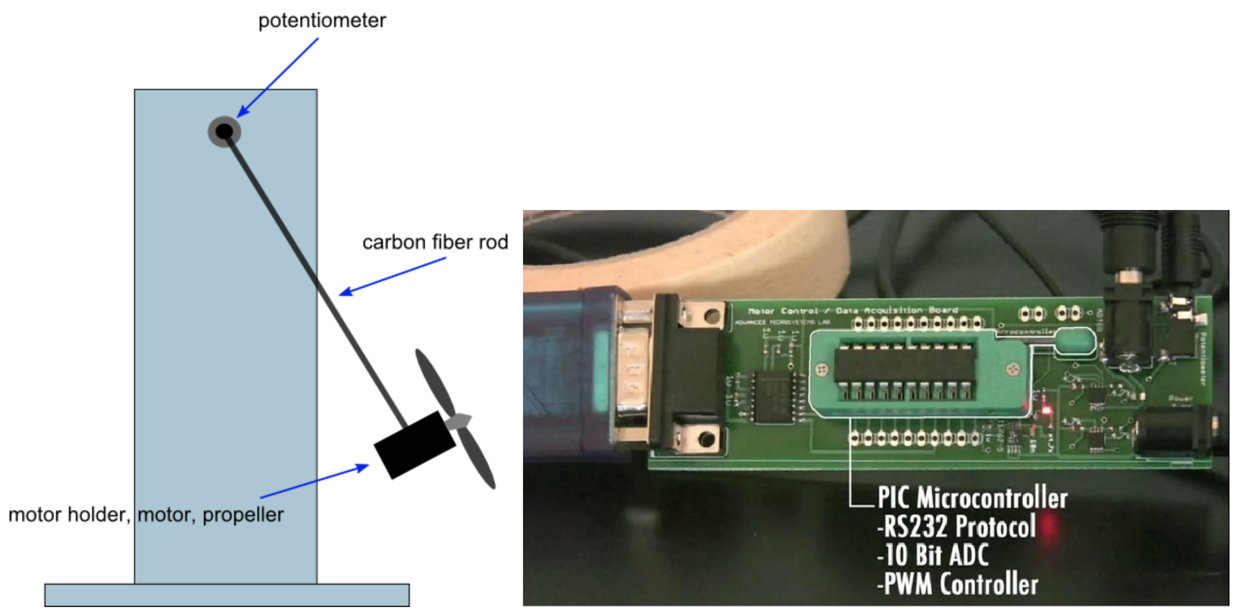


Fig. 1: Experimental apparatus: pendulum (left) and circuit board (right)

A 2-in propeller (model U-80) is attached to the motor shaft to produce a thrust force in order to control the angular position of the pendulum. A self-calibrating step during the initialization allows the system to automatically find the vertical position (origin of the coordinate system). A custom designed circuit board produces the controlled voltage supply for the motor via Pulse-Width Modulation (PWM) with a resolution of 0.05V. It also reads out the voltage on the potentiometer, which is proportional to the angular position of the pendulum. These functions are implemented using a Microchip PIC16F690 microcontroller, mounted on a ZIF socket for convenient replacement in case of damage or of need for reprogramming. The apparatus communicates with a PC through its serial port using RS-232 protocol and a Maxim MAX232 driver/receiver. For computers equipped with USB ports only, an RS232-to-USB adaptor is used (Model: PL2303, Prolific Inc.). Through this serial link the microcontroller sends the value of the potentiometer voltage measured by the built-in Analog-to-Digital Convertor (ADC), and receives the computed control signal, converting it to the respective PWM output to the motor. The PWM output is passed to an H-bridge formed by four MOS transistors, which produce the necessary current for the motor and allows bi-directional motor control. A MATLAB program (either an m-file or a Simulink model) residing in the PC receives the potentiometer voltage, computes the angular position of the pendulum, calculates the control signal from it, and sends it to back to the embedded processor for conversion to PWM. Both open loop and closed loop responses can be generated. The Matlab software also plots the pendulum angle in real time during the experiment (see Fig. 2 for an example). A LabVIEW version of the experiment has also been developed, however it was not used in the classroom yet.

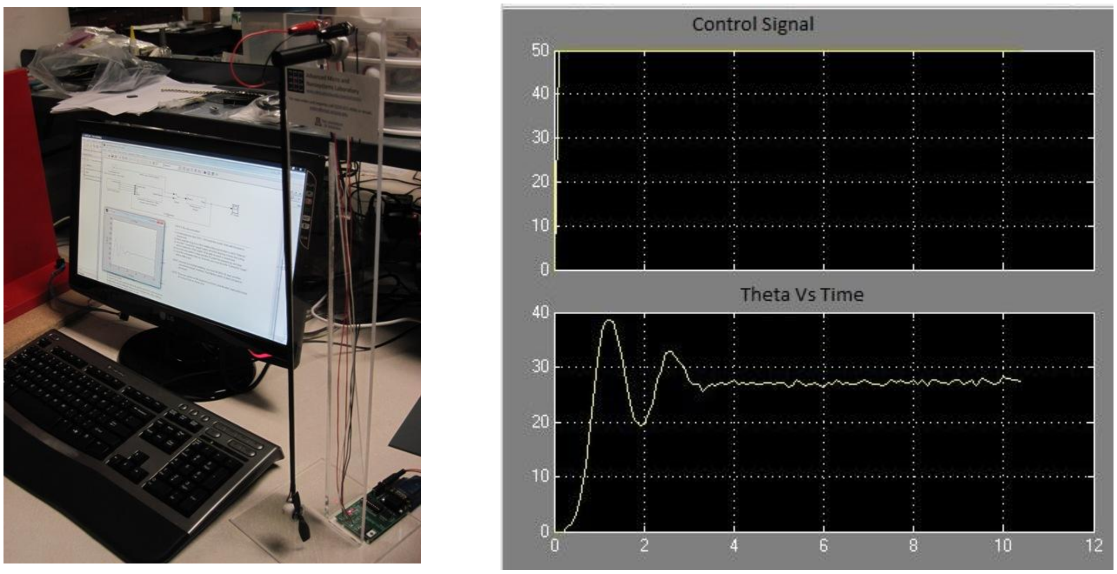


Fig. 2: Motor pendulum setup (left) and step-input response (right)

The experiment also illustrates the use of Matlab/Simulink Real Time Windows Target (RTW) environment. The RTW module performs classical control experiments using hardware in the loop simulations. Using RTW, the sampling time was reduced by an order of magnitude to 5ms. This is achieved by a built-in functionality of RTW that compiles the Simulink model down to C or C++ code, and then builds a native executable file. Removing the need for an interpreter greatly improves the efficiency of the simulation. Packet-In and Packet-Out blocks are used in the RTW model to communicate with the microcontroller on the custom printed circuit board. To receive the angle of the pendulum, the microcontroller must be asked to send the angle. This is a done via a Packet-Out block (see Fig. 3). Once the data is ready, the Packet-In block receives the raw voltage. A step function with a period of 5ms and a duty cycle of 50% is used to generate a query to the microprocessor every 5 ms.

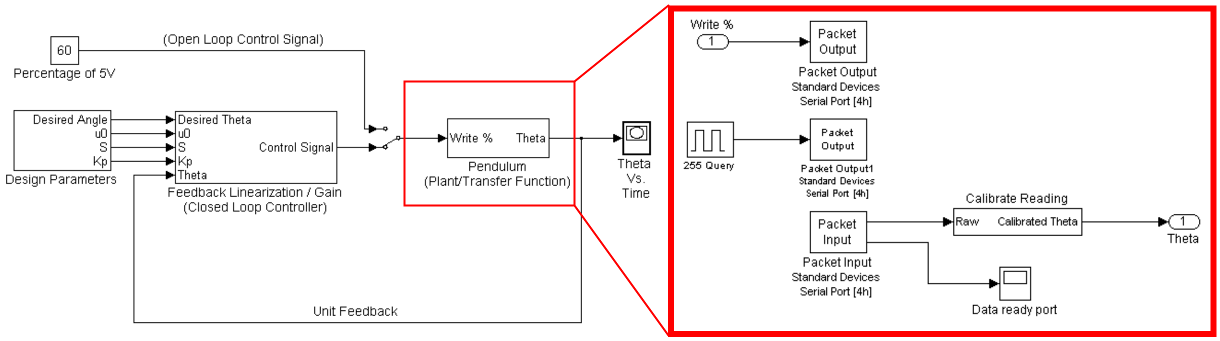


Fig. 3: Matlab/Simulink RTW implementation of the experiment

III. Description of student project assignment

The hardware described here has been tested with senior-year mechanical and aerospace engineering students taking their first and only mandatory course in controls system design. Prior to this experiment this course has been a lecture-only class, therefore the experiment had to be conducted as part of the regular homework assignments. Consequently, the students had to receive a detailed manual for the installation of the kit (www.nano.arizona.edu/mechatronics). The project assignment asks the students to develop a non-linear mathematical model of the pendulum and identify its physical parameters. The students focus on the dynamics of the pendulum, while the dynamics of the electronic components and the DC motor were assumed fast and negligible for the sake of this experiment. Typically, the students arrive at

$$mL^2\ddot{\theta} = -mgL\sin\theta - c\dot{\theta} + TL\,, \tag{1}$$

where mg is the weight of the motor, L is the length of the pendulum, c is the viscous friction coefficient, and T is the thrust force from the propeller. Students are then asked to use feedback linearization which cancels out the non-linear term in the form

$$T = mg\sin\theta + u\,. \tag{2}$$

The resulting linear system has a simple transfer function with two real poles

$$\frac{\theta(s)}{U(s)} = \frac{L}{mL^2 s^2 + cs}\,. \tag{3}$$

Students are asked to use their knowledge of root locus design method and determine the behavior of system (3) under closed loop control, i.e. to plot the root locus of (3) under proportional feedback. In the next step of the assignment, students are presented with the fact that for small values of the input voltage u, there is not thrust, i.e. the motor has internal dry friction preventing it from spinning until the voltage is approximately 1 V.
A simple non-linear model of this friction is given by

$$T = K(\tilde{u} - u_0), \quad \tilde{u} > u_0\,, \tag{4}$$

where u_0 is the threshold voltage needed to overcome friction, and K is a proportionality constant. Students are then asked to use a control law in the form $\tilde{u} = u_0 + S\sin\theta + u(t)$ and to show that under this law, the steady state angle of the pendulum θ_{ss} and the input voltage u_{ss} are related through a graph shown in Fig. 4 (left). They are then asked to show that by selecting the parameter $S = K/mg$, the resulting transfer function between the time varying input $u(t)$ and the output angle $\theta(t)$ is that of Fig.5. Using multiple open loop response experiments of this later system, students are able to identify numerical values of the parameters K/mL and c/mL^2.

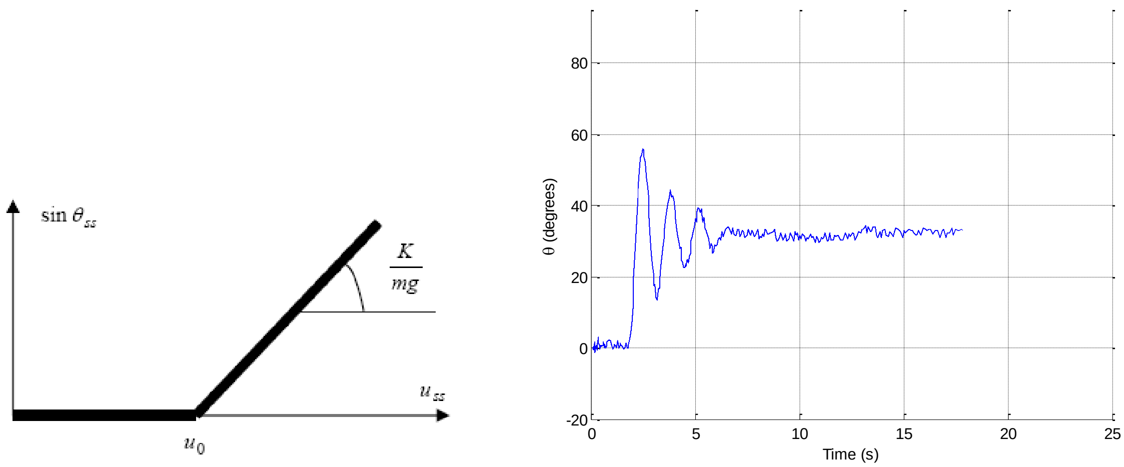
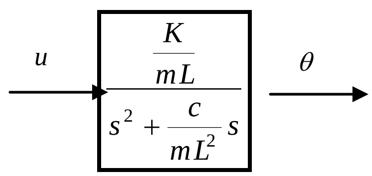


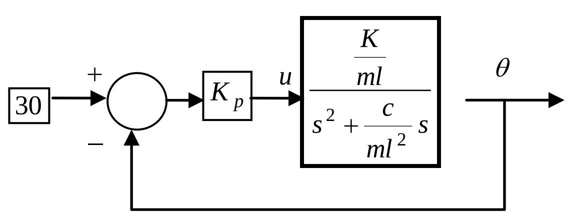
Fig. 4: Sine of the steady-state displacement angle vs. motor voltage (left) and open-loop response (right)



$$\frac{\frac{K}{mL}}{s^2 + \frac{c}{mL^2}s}$$

Fig.5: Transfer function of the feedback-linearized pendulum

Upon identifying the parameters of the system, the students are asked to implement proportional closed loop control according to the diagram of Fig. 6. Using root locus method, student predict that the system is stable under all values of K_p. However, when asked to run experiments for $K_p = 0.02;\ \ 0.05\ \ 0.3;\ \ 0.8;\ \ 1.0;\ \ 1.5$, they realize that for low values of the gain they obtain stable response as shown in Fig. 7, while beyond certain gain the system looses stability and the pendulum undergoes violent oscillations.



$$\frac{\frac{K}{ml}}{s^2 + \frac{c}{ml^2}s}$$

Fig. 6: Closed-loop control

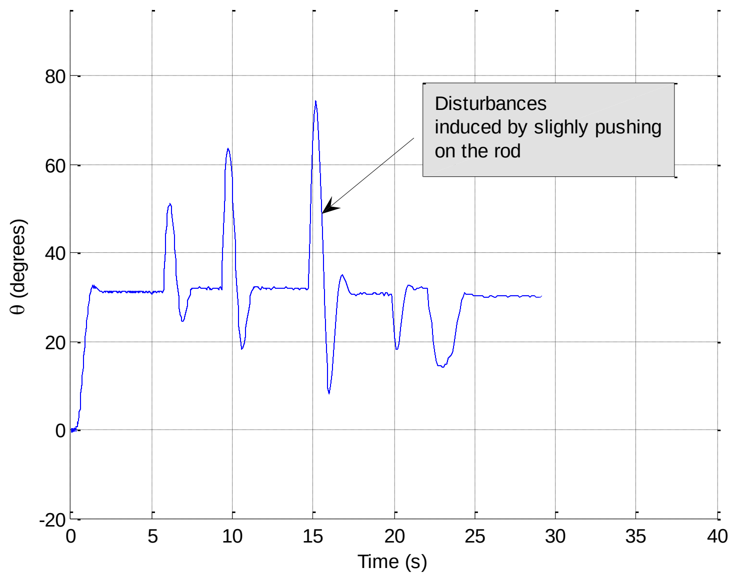


Fig. 7: Closed loop response

This experience leads to the third phase of the project which introduces the concept of time delay. Students are asked to augment their model with a first-order lag term (third pole added at $-2/T_D$) which models the time delay introduced by the digital sampling, data transfer. The time delay, T_D, varies based on the computer performance but is generally in the range of 30-50 ms. Using this additional information, they are able to modify their predictions by re-plotting the root locus of a third order system as shown in Fig. 8. Subsequent testing of the closed loop response does predict the correct stability limit of the closed loop gain.

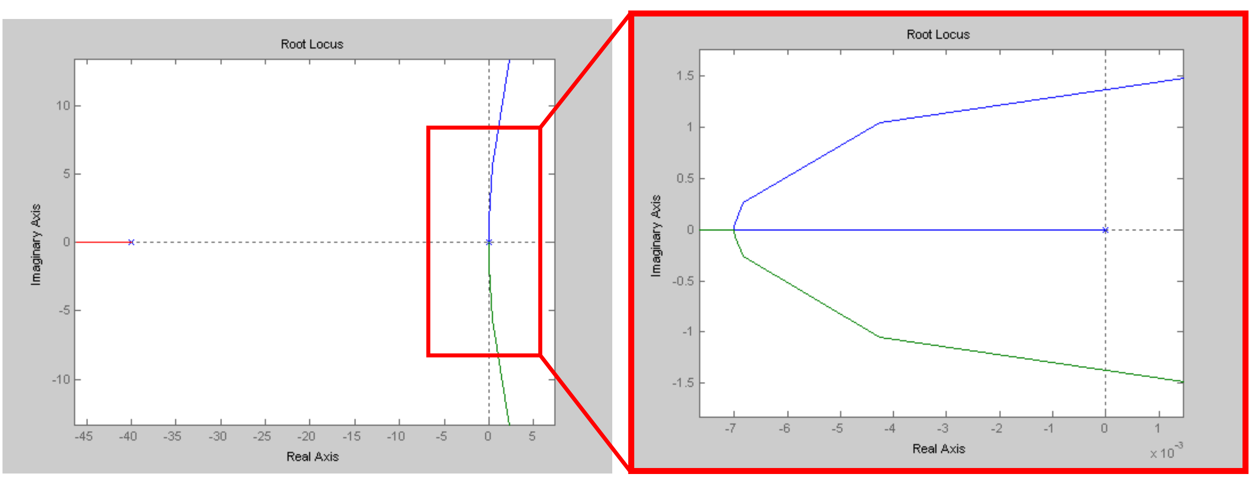


Fig. 8: Root locus of third-order system reflecting the effect of time delay

IV. Student experience assessment

An anonymous survey was conducted for the students choosing the project, to share their experience after the first semester this project setup was offered in the Control System Design course, following the protocol approved by the Institutional Review Board. As part of the evaluation students were asked questions about the technical content as well as the implementation and impact of the take-home project. Table 1 shows the evaluation of technical content. As expected the majority of the students found the system quite useful in illustrating the principles of control system design. Since frequency design methods were not used, the students correctly indicated that Bode plots were not illustrated (row 7 in Table 1).

Table 1. Student's technical experience assessment

To what extent (how well) did the project illustrate the following technical concepts?					
	Not at all	Less than expected	More than expected	Very well	Rating Average
Relation between physical system and transfer function	0.0% (0)	15.4% (4)	**50.0% (13)**	34.6% (9)	3.19
Second-order system response	0.0% (0)	15.4% (4)	**53.8% (14)**	30.8% (8)	3.15
Relationship between stability and gain	0.0% (0)	11.5% (3)	**46.2% (12)**	42.3% (11)	3.31
Relationship between overshoot and gain	0.0% (0)	30.8% (8)	**42.3% (11)**	26.9% (7)	2.96
Use of root locus	0.0% (0)	38.5% (10)	**42.3% (11)**	19.2% (5)	2.81
Use of Bode plots	**50.0% (13)**	26.9% (7)	19.2% (5)	3.8% (1)	1.77
System type and steady-state error	0.0% (0)	19.2% (5)	**57.7% (15)**	23.1% (6)	3.04
Disturbance rejection and system recovery	0.0% (0)	30.8% (8)	**53.8% (14)**	15.4% (4)	2.85
Non-linearity and ways to deal with it	0.0% (0)	**42.3% (11)**	30.8% (8)	26.9% (7)	2.85
Effects of time delay	0.0% (0)	38.5% (10)	**46.2% (12)**	15.4% (4)	2.77

As a comparison group, a paper-based term project was also offered. In the second part of the survey, we asked the students why they had chosen the hardware project over the paper-based one. The majority of them were excited by seeing the effect of the application of control theory to a tangible system. They were also interested in establishing a connection between the calculations and the experimental results. Comments such as "I was excited about the idea of actually seeing this design work on paper get implemented into a tangible mechanism…The hardware project offered a more real-world physical representation of control system design…It seemed more interesting to be able to apply the topic to a physical system rather than a theoretical controller design…"

The third set of questions referred to the implementation of the project, i.e. how portable and convenient the kit is, whether the students were able to find necessary data, and how needed was the assistance of a teaching assistant. The percentage of students who answered "yes" to each question is shown in Table 2. Interestingly, when the students were asked if they preferred to work in groups or individually, the majority indicated that teams of two to three students are the most preferred configuration. This is most commonly attributed to their desire to share work load and leverage off the different learning styles and skills within the group. Group work was encouraged, however each student was required to submit an individual report based on the data collected by the group.

Table 2. Project implementation assessment

Did not need a physical lab at all, I could do everything myself	56 %
Had to use the TA a bit, but 1 hr per week was enough	32 %
I needed to ask for additional assistance outside the 1 hr/week from the TA/instructor	8 %
The project should be done in a permanent lab with fixed operating hours and TA-s	4 %

Finally, we inquired about the impact the project had on other courses taken by students by administering a survey 6 months after completing the class. Students reported that the greatest contribution of the project was in using controls in their senior-year capstone design course. More than 50% of the students also indicated that they had used this experience in their job search by including it on their resumes.

V. Conclusion

An inexpensive (less than $100) take-home experimental setup has been designed for a hands-on experience of mechanical engineering students with a real control system. This makes it suitable for a term project, where minimal or no supervision is required, and no special time or place is needed. It also helps students whose major is not electrical engineering to become familiar with the modern developments in implementation of real-time control systems. While simple, the hardware allows demonstration of advanced concepts such as feedback linearization and time delay. Early evaluation data show that the project is well-received among students and it can be completed at home as initially conceived.

Acknowledgements

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Conceptual Change and Understanding in Engineering Education

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Introduction

In the study of science, technology, engineering and mathematics education there is a tradition of evidence showing that students – despite their abundant procedural knowledge and computational skills – lack understanding of fundamental physical phenomena. Students can be academically successful without internalizing the meaning of the problems and calculations they complete. For example, after an introductory physics course most students will be familiar with Newton's second law relating net force to acceleration, and will be able to apply it successfully in homework and exam problems. Research has found however[1, 2], that when asked to describe simple kinematics concepts, many students relate net force to velocity, instead of acceleration.

The disjunction between students' procedural conceptual knowledge was first noted in Halloun and Hestenes' work with their Force Concept Inventory (FCI). The FCI is a series of multiple-choice, qualitative questions that require students to make simple predictions (e.g. predicting where an object will go from a depiction of the forces acting on it) or judgments (e.g. identifying the acceleration of a thrown object at the peak of its trajectory). The average score on the FCI prior to instruction was 27%, and was shown to not change significantly after instruction[1, 2]. A number of similar assessments have been developed in engineering-related fields including thermodynamics, materials science, dynamics and statics[3, 4], with the same general findings: students' explanations of fundamental phenomena are often different than experts, but show some commonality with other students' explanations.

A logical research agenda arising from this finding is to investigate why some forms of learning (i.e. conceptual understanding) are so much more difficult than other forms (i.e. procedural knowledge). In Halloun and Hestenes' work, and most subsequent studies, the pervasiveness and persistence of student conceptual difficulties was explained by the constructivist assumption that every student brings a "common sense"[5] understanding of the world to the study of physics. This means that learning requires changing a students' knowledge in addition to adding to it. During the normal course of life people explain the world around them in terms of the informal observations they make. All students who enter an introductory physics course have experienced gravity, acceleration and magnetism, and have developed a way of explaining their experiences. Most students have not developed equations and performed calculations based on their experiences, so procedural knowledge can be gained without changing any existing understandings. Halloun and Hestenes found, however, that in many cases common experiences lead to incorrect generalizations about the world. Newton's first law, for example, implies that objects in motion will naturally stay in motion until something stops them. This is in direct conflict with everyday experiences in which effort is always required to keep an object in motion. The difficult process of learning new material that contradicts existing knowledge and ways of thinking is called conceptual change.

The field of research that has developed around questions conceptual change has not been broadly utilized in engineering education research. The purpose of this paper is to present the two leading theories of conceptual change, examples of current research in this area, and how they can be applied to engineering teaching and learning.

Why Does Conceptual Change Matter?

It is worth briefly presenting the argument for considering conceptual change in engineering education research. Although students' scores on concept inventories surprise many instructors, the implications of low conceptual understanding in engineering are not often discussed. In the highly regulated apprenticeship system of engineering, graduates who are adept at calculations may be all that is needed. While the complete arguments on both sides of this issue are too involved to include here (and most likely will require future research to truly illuminate), we would like to highlight two key components of conceptual understanding that make it particularly important for practicing engineers. First, conceptual understanding is the type of flexible, abstracted knowledge that has been shown to be transferable, whereas procedural knowledge often only be applied in the context in which it was learned[6]. This means that students who are not developing conceptual understanding may be severely limited in their ability to apply their knowledge as practicing engineers unless the context of the work is sufficiently similar to the context of the learning. Secondly, conceptual understanding is longer-lived than procedural knowledge by definition. This is basically another way of stating the consistent finding that students' conceptual understanding is resistant to change. This means, however, that once productive conceptual understanding is established, it will take concerted effort over time to change: it cannot simply be forgotten in the same way memorized procedures or facts can be.

Theoretical Approaches to Conceptual Change

This paper will discuss the theoretical approaches of Michelene Chi and Stella Vosniadou. These two theories were chosen because they have the most explicit implications for engineering, and because they are the most richly developed and empirically validated. These two theorists do not represent the range of conceptual change research approaches, however. There are two primary divisions in conceptual change research: pieces versus coherence, and individual versus social cognition. In the pieces-versus-coherence debate, the primary issue is how organized and interrelated naïve student knowledge is[7]. The pieces view is characterized by Andrea diSessa's theory that naïve student knowledge acts as a loosely connected network of thousands of experience-based beliefs, and that conceptual change is the process of organizing these beliefs into a hierarchical system[8]. Both Chi and Vosniadou's work considers naïve student knowledge to be more coherent in that it is already organized into a hierarchical system and that conceptual change is required when this system conflicts with new information. The individual versus social cognition debate is concerned with how best to define knowledge. Most researchers (including Vosniadou, Chi and diSessa) consider knowledge to reside within individuals. Proponents of situated cognition argue that because knowledge is always acquired, changed and assessed through social interactions, it is best to consider it as a social construct[9]. In this view, approaches that do not account for socially situated effects such as interviewer-interviewee interactions or resources are overly limited.

Vosniadou's Framework Theories

Stella Vosniadou's approach to conceptual change is based on the theories students use to explain the world prior to science education. She defines a theory as a "…a relatively coherent body of domain specific knowledge that is characterized by a distinct ontology and a causality and can give rise to prediction and explanation" [10]. These theories exist at different levels of specificity, but Vosniadou proposes that what she calls the "framework" level is the most important in conceptual change.

Framework theories are domain-specific applications of a person's ontological assumptions about the universe. These ontological assumptions are universally applied to all of a person's knowledge and learning endeavors, but they have somewhat different consequences when applied to different domains of human experience. For example, a person may assume that the universe is non-intentional and behaves only in accordance with objective laws. This assumption may find direct expression in the study of physics, but be relatively unimportant in the study of sociology because people are understood as exercising agency, and therefore can't be assumed to be non-intentional.

The power of Vosniadou's framework theories is that they can be used to explain why some types of learning are more difficult than others. As the level of abstractness increases the learning processes become more difficult and lengthy due to the relative strength of the convictions and the students' own unawareness of them [11]. In this use, the word "abstractness" refers to the generality of the knowledge's application, or its inductive distance from experiences and observations. The strength of the convictions at each level of abstractness can be thought of as the breadth of their impacts if changed. Specific beliefs (e.g. that the rate of acceleration due to gravity is 32.2 feet per second per second) are the most easily changed, because they may require the modification of a few closely related beliefs.

Vosniadou states that belief revision is the easiest form of learning, and is therefore the dominant form during education[12]. In Vosniadou's approach, the learning of procedural knowledge could be thought of as the addition of new beliefs. The challenge for students, however, and the reason that conceptual understanding doesn't develop at the same rate as procedural knowledge, is that mental models are not often explicitly addressed in education. Students are told that force equals mass times acceleration, and they accept this as a new belief, but do not revise their mental models of motion in which forces result in movement which is characterized as velocity. When a student modifies or enriches their beliefs through education, but doesn't adjust their mental models or framework theories to accommodate the new beliefs, contradictions arise[13]. Vosniadou calls these contradictions "synthetic models," in that they are an artificially created hybrid of a students' own beliefs and those presented during instruction. In a description of children's conceptions of the shape of the earth[12], Vosniadou visually represented three synthetic models in which children had combined their experience of a flat earth with aspects of the spherical earth described in their education. These models include a "dual earth" model, in which there is a flat earth that people walk on and a spherical one in space, and a "hollow earth" model in which the earth is like a spherical fishbowl partially filled with soil that creates a flat surface for people to stand on. Synthetic models are problematic for students because they limit the explanatory and predictive power of their understanding. Synthetic models are key to understanding why it is more difficult to acquire conceptual understanding. Vosniadou writes, "[w]e argue that many science concepts are difficult to learn because they are embedded within scientific framework that violate fundamental principles of the naïve, framework theory of physics within which everyday physics concepts are subsumed" [12].

Chi's Types of Learning

Michelene Chi's describes three types of learning that are of key importance in science education: belief revision, mental model transformation and categorical shift [14]. Chi states that belief revision is relatively simple, even when new knowledge is in contradiction to students' existing beliefs [14]. Similarly, mental model transformation can be accomplished by direct presentation of contradictory information. Chi states that "…the accumulation of numerous belief revisions eventually result[s] in the transformation of a student's flawed mental model to the correct model…by-and-large"[14].

The truly difficult type of learning, and the process that Chi theorizes accounts for student difficulty in developing conceptual understanding, is what Chi calls categorical shift[15]. The categories referred to in the phrase "categorical shift" are most easily understood in terms of the cognitive and perceptual processes they relate to. Piaget, a seminal theorist in educational psychology hypothesized that in order to efficiently interact with the amazing variety of objects humans experience, a process of categorization and recognition is used[16]. Common life experience will support the hypothesis humans usually relate to objects based on previous interactions with similar objects. Although new styles of chair are designed each year, most people are able to very quickly identify these objects as chairs, and use their previous experiences with chairs to determine what to do with the models. This remarkable efficiency and flexibility is due to the process of categorization[17]. A categorical shift, then, is required when a learner miscategorizes an object.

Chi states that the persistent difficulty of developing conceptual understanding is due to the difficult in creating and revising categories. In particular, learning in science is hampered by the presence of two persistent misconceptions: the miscategorization of processes as substances, and the lack of a category for emergent processes[14]. Chi has found that many students think of heat as a substance that flows, while physicists describe heat as a process of energy transfer. A student, for example, would explain that opening a window on a cool day would cool a room because the heat can leave the room, but a physicist's explanation would include the transfer of energy between air in the room and the air outside. This miscategorization cannot be addressed through belief revision[18]. Furthermore, the categorization of heat as a substance actually interferes with belief revision[19]. Student difficulty in learning about heat is exacerbated by the fact that it is an emergent process. Emergent processes are those in which easily observed phenomena are the result of non-directional, random and often unobserved interactions, and are defined in contrast to direct processes in which goal-driven agents work sequentially in a visible causal chain. A common example of an emergent process is the tendency of flocks of migrating birds to fly in V-shaped formations. This is currently understood as an emergent process in which each bird reacts independently to their sensations of wind resistance. This is not a direct process, because the birds are not trying to form a V, and are therefore not basing their position on the positions of other birds. Similarly, heat is an emergent process because the energy transfer occurs due to the relative probabilities of high energy and lower energy molecules interacting; if it were a direct process, the energy transfer would be due to an observable macro-scale phenomenon like a temperature gradient. Chi proposes that most students do not possess an ontological category for emergent processes, and therefore classify all processes as direct.

As explained above, cognitive categories are used to interpret new experiences, including new information presented during instruction. This means when a student miscategorizes heat as a substance, everything they learn about heat will be interpreted to fit within the category of substance, and information that contradicts this or does not fit within the category will be discarded or changed[19]. For example, because heat is a process it can be said to have a duration, but coffee, which is a substance, cannot. A student who hears statements referring to "how long the heat lasts" will interpret this statement to mean "how long it takes for the heat to flow away" just as they would when hearing a similar statement about coffee. A similar statement about brewing coffee, something which is unproblematically categorized as a process, will be taken to refer to the duration of the process. In order to develop conceptual understanding of electricity or heat, therefore, students have to become aware of the need for recategorization before even beginning the difficult process. Chi states that developing awareness of when conceptual change is necessary may be the most important barrier to conceptual change. She writes, "[b]ecause students are able to generate predictable responses to questions and systematic explanations of phenomena, they don't notice that their model is incorrect"[19].

Implications for Engineering Education Practice

As argued above, engineers need conceptual understanding of physical phenomena in order to be flexible, efficient problem-solvers. Vosniadou and Chi's explanations of why and how that conceptual understanding can be so difficult to develop have some important implications for the practice of educating engineers.

Intention in Conceptual Change

First, the required revisions to framework theories and categorizations are difficult, and require intentional effort on the part of the learner[20]. Even given willing and motivated students, the educator must first make them aware of their abstract-level misconceptions. As Chi writes,

> The issue of awareness is easily addressed, in theory. All one would have to do is tell the student that he or she is wrong, and confront them with information and demonstrations that show the student's understanding to be flawed. One can even explain the correct principles to the students. However, in practice, this does not always lead to a more accurate, deeper understanding. As described earlier, one may directly refute or contradict a misconception with little or no effect.[19]

To clarify, when Chi writes "directly refute or contradict" it is in the context of her research based on students' understanding of written information. There is a proven methodology to encourage students to refute and contradict their own misconceptions. The first step is for research to identify the particular misconceptions in the field of study. Introductory physics is the most thoroughly investigated field in this way, and exhaustive taxonomies of misconceptions have been developed [5, 21]. While many physics concepts are applicable to engineering, little research has been done investigating common misconceptions in engineering-specific disciplines such as fluid mechanics or mechanics of materials[22].

Research in physics education has shown that once misconceptions have been identified they can be effectively addressed in the classroom by encouraging students' inductive reasoning[2, 23, 24]. Practically, students are presented with problems designed to elicit incorrect categorizations or framework theories and are encouraged to explain their own errors. This can be thought of as the instructor orchestrating experiences from which students can generalize correct scientific phenomena of the world. As stated above, common experiences in life can often lead to incorrect generalizations. Once these generalizations have been identified by research, problem sets, experiments and activities can be designed to create experiences that challenge the incorrect generalizations.

By forcing students to make predictions and explanations based on expected misconceptions instructors are able to make the abstract levels of students' knowledge more explicit. This process is primarily up to the student however; instructors can only go so far in helping students reflect on their own thinking. Chi has suggested that one aspect of science education should be explicit instruction in the metacognitive processes required for conceptual change[25]. Successful approaches have at least partially addressed this challenge by focusing on specific misconceptions, as opposed to the more systematic conceptual difficulties students are theorized to possess. In this way students can continue to work at the belief-level with which they are familiar, and only make minor conceptual changes during any given lesson. This is obviously less efficient than an ideal instructional method that would lead students to adjust their miscategorizations and framework theories holistically, but such a method has not yet been designed.

Emergent Processes and Synthetic Models in Engineering

Engineers in any discipline will have to understand and manage emergent processes. Examples range in scale and scope and include the evolution of stresses in members under bending, the function of microbial communities in bioremediation, structural failure of bridges, and traffic flow dynamics. In the absence of research identifying specific misconceptions in most domains of engineering, instructors could identify subjects of probable conceptual difficulty by identifying the emergent processes covered in their courses. As explained by Chi, students will first need to be taught about the category of emergent process before they can successfully categorize or recategorize processes as emergent. As in Chi's papers[14, 19], such instruction could leverage people's intuitive understanding of direct processes to explain emergent processes by emphasizing the divergence from direct processes.

The context-specific way in which science is taught in engineering may promote the creation of more synthetic models. For example, most engineering students take a course based on the analysis of static bodies. The beliefs accumulated and revised through this very specific application of Newtonian physics may are not likely to induce changes in the students' framework theories. These synthetic theories then serve to compartmentalize students' knowledge, because they create inappropriate contextual limitations. Students may develop conceptual understanding of free body diagrams in terms of trusses (a commonly used example in statics textbooks), but be unable to apply that understanding to the analysis of internal forces in structural members because each application is organized under its own synthetic framework theory. For educators, this provides an explanation of the commonly expressed frustration that students seem unable to apply knowledge across courses. It also provides a means of addressing that frustration because once synthetic models have been identified, they too can be elicited and contradicted in class. In this way, instructors will be able to move beyond ineffectually contradicting incorrect student beliefs and on to helping students address the sources of those beliefs.

Conclusion

A theoretical understanding of conceptual change has direct implications for the practice of engineering education. Vosniadou and Chi have developed clear means of characterizing students' previously developed conceptual knowledge, which will allow engineering educators to answer persistent questions about why certain concepts are more difficult to learn, and why students may seem to inappropriately compartmentalize their knowledge. In order to educate engineers who are capable of applying their fundamental understandings of science to diverse societal problems, educators need to be aware of the importance of this level of students' knowledge, and the role it plays in learning.

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Engineering Economy with "Green" and Energy Evaluations

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Abstract

The core material of an engineering economy class is the mathematical means to evaluate money through time and the concepts of project evaluation in terms of engineering limitations and financial considerations. The students use these tools to evaluate contemporary "green" topics that they have researched. One class considered the economics of recycling. Another class has researched the implications of various means of commercial electric generation. In both cases, the individual students acquire an expertise in a single area of the project and contribute that knowledge during the period, in-class group analysis and discussions.

Teaching an introductory, under-graduate class in engineering economy involves all of the arithmetic involving interest, annualized payments, inflation, and future worth. It involves the analysis of the decision-making process involving both engineering and economic criteria. The Joseph Hartman's textbook provides a wealth of information. The class also provides the forum for the critical evaluation of current topics based on the economic understanding discerned from the core material. It also allows for the inclusion of several of the criteria on which engineering programs are evaluated. During the past two semesters, this endeavor has been focused on the "green" topics ever present in printed media and political discussions.

By incorporating these topics into the class, the educational impact includes a broader, even global, understanding of the relationship between engineering solutions and the environmental and societal implications. It forces an economic and engineering evaluation of broad-reaching contemporary issues. It allows for the in-class articulation of relevant information by the students and it encourages the analysis of out-of-class issues in light of their education to date, a skill it is hoped will remain with them throughout their lives.

One class delved into an economic evaluation of recycling. The area surrounding the University has no recycling. Although the community is attempting to initiate that service on a limited basis, no broad recycling exists. The project was kicked-off with an in-class discussion. The students, who had spent five weeks in class learning to think of engineering issues in terms of economic analysis, were able to list many facets of recycling the economic viability of which are key factors in the success of a complete program. The students selected key elements in any recycling program and researched the economic implications. These topics included pick-up, sorting, local processing and marketing, transportation to out-of-town processing centers, per

pound values of both sorted and fully processed material, and community financial and moral support.
The on-line research by the students was augmented by two guest speakers. The first speaker was a representative from the city and county Department of Health. The speaker had experience in expanding a working recycling program in California in a prior professional position and was instrumental in initiating a limited recycling program locally. She expanded their understanding of the germane issues and, through their research, the students were able to ask informed and pointed questions.

The second speaker was from a local economic expansion group. She addressed funding alternatives and her perception of the value of an existing recycling program in the decision process of corporate relocation. Again, the students were able to expand their understanding of important economic concepts by asking informed questions of this subject matter expert.

The semester project culminated with short presentations on the various related topics and an excellent class discussion analyzing the existing economic negatives associated with initiating a recycling program. Each student wrote a short paper documenting their findings on the topic they chose. The papers were copied, collated, combined and distributed back to the class.

The next semester of this introductory, undergraduate engineering economy class looked into energy alternatives. The topic is ever present as a local, state, and national issue. The individual students selected topics of interest to them in either the renewable or more traditional energy production areas. Each student was asked to arm himself with topic data relevant to an economic discussion in class. Numerical information on such things as construction costs per installation and in terms of power units produced, footprints, maintenance, and supply chain work forces were suggested. Dollar values were leveled with costs reduced to “per kilowatt” dollar values.

During the end of at least one of the two class periods each week, the class time would be concluded with a discussion of what new information had been discovered regarding their energy alternative research. The context was moved into areas relevant to the engineering economics class. As the semester progressed, more students were able contribute to the information sharing in the classroom. Every student in the class was able to add to the information pool as the semester continued. The students were good at sharing things that they had found that surprised them, especially the cost per kilowatt, foot print required for each large system, and the economic impact to the consumer. The graduate students in the class were required to document their research in a formal paper.

Economic issues were the primary topic of discussion. When political or global warming issues were inserted into the discussion, the analysis was steered into less polarizing territory. Non-economic issues were limited to concepts involving public perception and the “not-in-my-back-yard” philosophy. In the end, the comparisons were based on available economic information and the certain work-force considerations.

In addition to learning the economic implications of engineering decisions from the material in the text, the students had the opportunity to research and share information on current, relevant engineering topics that will remain in their world for their lifetime. The research and discussions led to the evaluation and analysis of real topics that have contemporary social and professional implications. It was felt the students gained an appreciation of the necessity for critical thinking and economic evaluation of topics beyond the text and of importance to the world.

There is no assessment to measure the success of this tact in the engineering economics class. The students seem to enjoy the application of their education to real world issues. This instructor has found the sharing of information enlightening. The students eagerly engaged in the conversations; it appeared as there was some interest on their part.

The introduction of relevant economic and social current event topics into the engineering economics course content had many advantages. It provided a contemporary backdrop for the core material in the class. It allowed the students to research and share topics of interest to them. And it allowed the students to become engaged in the class discussions. This activity will continue to be inserted into the engineering economy content whenever the class is taught. The current state of the world provides a rich environment from which to chose topics.

Work in Progress: Understanding Student and Workplace Writing in Civil Engineering

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Abstract

This project addresses a continuing problem in engineering education: the mismatch between the writing skills of engineering program graduates and the demands of writing in the workplace. The project, funded in part by the National Science Foundation's Course, Curriculum and Laboratory Improvement program, takes a new approach to investigating the problem and devising instructional materials because it is based on a large-scale investigation of the organization, grammar, and vocabulary in texts written by numerous students and practitioners. It uses computer-assisted analysis techniques from the field of applied linguistics and involves collaboration among applied linguists, engineering faculty, and engineering practitioners. Although school tasks are produced for different purposes and audiences than workplace writing, the multiple perspectives brought to the study allow us to identify aspects of student writing that are counter to practitioner concerns and are not the result of a class requirement. These areas can then be targeted for writing instruction. Although the project focuses on civil engineering, the approach can be applied to any field.

Introduction: The Problem and Context

Surveys of engineering program graduates and their employers consistently identify writing skills as a problematic area in new engineers' preparation[1]. This problem is especially important for the civil engineering program participating in this study since virtually all students in the program hope to work as civil engineers when they graduate. However, there is little research describing exactly how student writing in civil engineering differs from practitioner writing. Though much has been written about engineering writing, it rarely emphasizes civil engineering or analyzes typical practitioner writing. The present project is innovative in undertaking a comprehensive analysis of the language and organization in a large number of texts written by undergraduate students and practitioners in civil engineering, and using the results to inform instructional materials.

Analytical Approach

The project uses "corpus linguistics" – a research approach developed in the field of applied linguistics that combines quantitative and qualitative analysis of large collections of texts through the use of computer-assisted techniques. Over 500 written texts are being collected, representing writing by students in a variety of classes and consulting engineers from a variety of firms, and covering multiple genres (e.g. reports, proposals, work-related e-mail, etc.). The large number and diversity of texts and writers allows investigation of both typical patterns and variation in the language used by the student and practitioner groups. The analysis covers four main areas: vocabulary, grammatical structures, organization, and rhetorical functions. (Rhetorical functions are specific purposes for parts of a paper such as “state purpose of communication,” “report results of analysis,” and “make recommendations.”). The differences among genres and between the student and practitioner texts are interpreted with the input of the multidisciplinary project team that includes applied linguists (who study language variation in different communication contexts), engineering faculty, and engineers in local consulting firms. Interviews with student writers provide an additional perspective.

Preliminary Results

This two-year project is currently in its first year. Results are thus preliminary. Here we provide an example of the results comparing student and practitioner design reports. Although the organization of the texts is largely similar, the language has several notable differences.

One striking difference is student vocabulary choices that are counter to practitioner concerns about professional liability and precise description of professional practices. Students are far more likely to use absolutes and superlatives – for example, they *determine* design parameters and present the *best choice* whereas practitioners *estimate* and *calculate* parameters and discuss the *preferred* option. At first glance, these may appear to be superficial, unimportant differences; however, precision and liability are primary concerns for practitioners. Student comments imply that they consider *estimate*, *calculate*, and *determine* to be synonyms, and many were taught in some past writing class that variety in vocabulary is good. From a practitioner perspective, each word has a distinct meaning and different contractual implications. While liability is discussed in the civil engineering classes, few students realize its connection to word choices, and liability is in fact completely neglected in many published writing guides. Another difference is higher frequencies of dependent clauses and passive voice in student writing over practitioner writing. These features result in long sentences in student writing that are difficult to understand, contain extraneous or misplaced information, and are often grammatically incorrect. Experienced practitioners instead use simpler sentence structures and more active voice; the result is sentences that are easier to understand and have a clearer step-by-step progression through information.

Teaching materials will be developed in the second year of the project. It is clear already, however, that materials must integrate language information with specific civil engineering concerns, content and professional judgments. Advice to “be precise,” for example, is too general to be helpful unless coupled with knowledge of how to precisely describe civil engineering practices. Fortunately, writing assignments that are already a regular part of the program appear to provide plenty of contexts for working on writing skills that can help make students better prepared for writing in the workplace.

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The Relationship between Self Efficacy, Critical Thinking, Grades, and the Quality of First Year Engineering Students

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Abstract

It is hypothesized that four qualities including strong content knowledge, good critical thinking skills, high self efficacy, and a high cognitive thinking level define a successful student. In an effort to increase these qualities in first year engineering students at the University of Nevada, Reno, new course content was developed for a pair of first-year classes, which also utilized teaching methods that were customized to how people learn most efficiently. Analysis of Variance (ANOVA) and Pearson's correlation were used to study the relationship between content knowledge, self efficacy, cognitive level, and critical thinking level.

It was found that critical thinking and self efficacy scores are positively correlated with each other, but neither is correlated with the student's course grade. In addition students who stated that they believed they would earn an 'A' in the first year course performed significantly better in critical thinking. Critical thinking and self efficacy scores did not have a correlation with overall course grades, which suggests that course grades may not be the best method for defining the quality of a student. This research supports the common belief held by many faculty: student grades are not the best indicator of student quality.

Introduction

Critical thinking is the process of gathering information and actively analyzing, synthesizing, applying, or evaluating it in order to make decisions, form beliefs, or choose a course of action [1]. Increasing engineering students' critical thinking skills is important because the higher their critical thinking level, the more successful they will be in solving problems. Students must think critically in order to gather data to solve problems, defend their solutions to problems, make open minded decisions, and communicate their ideas.

Critical thinking is typically measured in terms of skills associated with analysis, inference, evaluation, inductive reasoning, and deductive reasoning to give a total critical thinking skill score. Analysis skills are employed to dissect arguments that separate the assumptions a person is making from the conclusions they have drawn based on those assumptions. Inference skills are used to draw conclusions based on concrete evidence and rationale. Evaluation skills are those used to determine if an argument or idea is believable. Inductive reasoning skills are employed when we use what we know to infer a correct answer. Deductive reasoning leads us to believe something cannot be false if all of the foundations of our argument are true [2].

Self Efficacy refers to one's beliefs in their capabilities to organize and execute the courses of action required to produce given attainments [3].Self efficacy affects the choice of actions that people take, the manner of which they complete those actions, the effort, stress, perseverance, and resilience they exhibit when faced with challenges to completing their goals, and the level of success they reach [3, 4]. Self esteem and self efficacy are closely related and important to education, but they are fundamentally different. While self esteem answers the question, "how good of a person am I?" self efficacy answers the question, "how well can I accomplish this task?" [5].

Self efficacy affects how students perform in solving engineering problems, as well as their retention in engineering curriculums. Professors can help students increase their self efficacy by providing goals, encouragement, mastery experiences, vicarious experiences, and stress coping strategies which will help students be more successful in engineering classes [4].

Since we know that self efficacy affects student success level it is important to not only provide ways to increase self efficacy, but also to monitor self efficacy. Bandura [3] has clear guidelines for designing self efficacy surveys. He stresses that when constructing self efficacy scales, one should make sure they are measuring self efficacy, or belief in one's capability, not self esteem, which is belief in one's self. The standard method for constructing a self efficacy survey is to ask individuals to rate their belief in their ability to perform a specific task. Subjects rate their efficacy on a likert scale that ranges from zero or no confidence to 100 or high confidence.

Cognition is the process of knowing, applying knowledge, and changing preferences. There are two popular methods for measuring cognitive levels including Perry's Model and King and Kitchener's Reflective Judgment (RJ) model. Both models are similar in classification although Perry's model contains two extra positions at the higher end of the scale [6, 7].

According to one major study that utilized the RJ model, engineering freshmen start and end college with a slightly higher cognitive level than liberal arts students, however, their cognitive growth over four years of college is less than liberal arts majors [7]. The small growth in cognitive levels during college could be a problem for engineering students in the future because of globalization. As the world becomes flatter due to advances in communication and ease of travel, American engineering graduates may find their jobs being outsourced to their foreign counterparts who can and will work for much less money [8, 9]. Low cognitive levels are also a problem for engineers because it affects their decision making skills. People need to think cognitively at higher levels in order to make educated decisions, which they are able to defend in order to survive in the current job market [10].

Grades are often seen as a measure for program and knowledge evaluation, but they often are not a true measure of ability. Programs that have students in them with higher grades on average are often seen as more successful programs, but these grades are often impure measures of ability [4]. When people evaluate grades, they do not know the inherent variation or history of the grade. Grades are subject to numerous variables, independent of student ability and effort, including tough and easy professors, inflation within the university or program culture, curves applied to the class, etc. Rojstaczar created a web site to highlight the rise of grades in colleges and universities. He claims that grades continue to rise despite the fact that students spend half the time studying now than students enrolled in college 40 years ago. The average grade point averages (GPAs) at public and private universities were 3.0 and 3.3 respectively in 2007 [11]. Figure 1 shows a gradual inflation of GPA for 70 private and public universities in the United States [12].

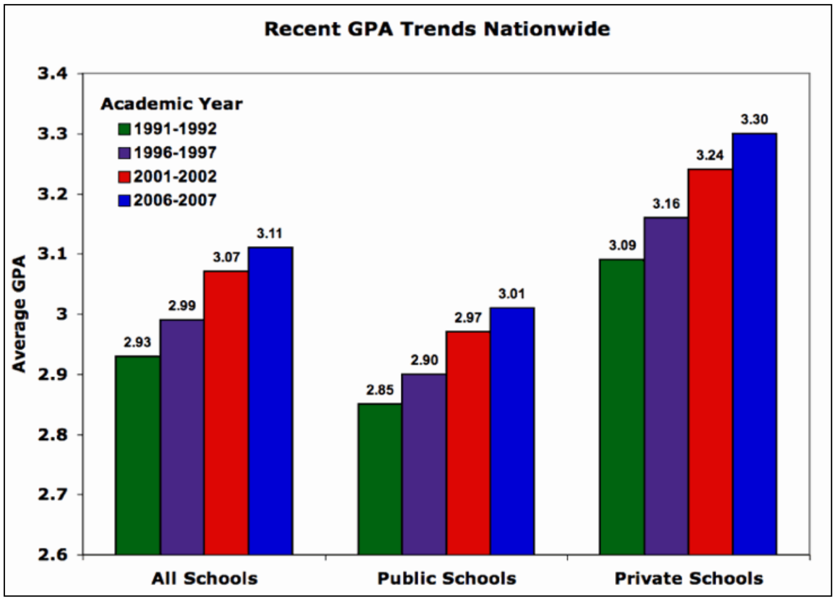


Figure 1 shows nationwide grade inflation trends. All universities had an average increase in GPA of 0.18 on a 4 point scale between 1991 and 2007.

The objective of this research was to determine if critical thinking, self efficacy, and grades are correlated in any way. This research was motivated by the common belief held by many faculty: student grades are not the best indicator of student quality.

Methods

Sampling

The Mechanical Engineering (ME) and Material Science Engineering (MSE) Departments at the University of Nevada, Reno have developed a required multi-disciplinary first-year engineering course with funding from the William and Flora Hewlett Foundation [13]. Traditionally this course has a combined enrollment of approximately 150 students.

The course is held in a computer laboratory with 24 students at a time, working in pairs. The class alternates between a workshop and a mini design project every other week. During the weeks in which a workshop format is used, the class consists of an interrupted lecture where students alternate between listening for brief periods and then actively participating (i.e., programming). LEGO® robots were used so that students would have a tangible application for their computer programs. Projects and assignments were designed to improve critical thinking skills and cognitive development.

Participants in this study were all mechanical engineering students enrolled in this interdisciplinary course in the spring of 2009, who volunteered to take a critical thinking test and several self efficacy surveys. Subjects were mainly freshmen between the ages of 18 and 20.

The authors evaluated the quiz scores and final grades of the students who participated in both the critical thinking test and the self efficacy surveys. Researchers did not expect the quiz scores, critical thinking scores, and self efficacy scores to correlate significantly with final grades, since final grades are curved in this class. An application was submitted and approved with the Institutional Review Board (IRB) so that the critical thinking tests could be given and the results published.

Critical thinking tests

This research utilized the California Critical Thinking Skills Test (CCTST) to determine critical thinking levels because it has an appropriate level of difficulty for college students, it is easy to obtain and administer, and it is relatively inexpensive. The CCTST covers the five critical thinking skills identified by the Delphi experts including analysis, inference, evaluation, inductive reasoning, and deductive reasoning skills [2]. The CCTST is a multiple choice test offered online that takes approximately 45 minutes to complete.

Self Efficacy Tests

Self Efficacy was tested using a survey, created by the authors, based on Bandura's guide to constructing self efficacy scales [14]. The survey was given online, via SurveyMonkey.com, four times to the students during the spring of 2009. The first 4 groups of questions on the self efficacy survey involved students ranking, on a scale of 0-100, their degree of confidence, how much they value being able to perform, how successful they would be, and their anxiety level toward a list of tasks that make up the 10 learning objectives for course. Details concerning the learning objectives have been previously published [15]. Total self efficacy was determined to be the average value of the student's response.

Cognitive Development Essays

In this research, the cognitive level of each student will be tested via review of writing samples that were designed based on classic cognitive level interview questions. Students provided approximately 7 writing samples in during the semester. With these samples researchers will determine the student's level of cognitive development according to the RJ model, which will be used as the quantifiable measure of cognitive development. This portion of the research is currently in process and, thus, no results will be presented.

Content Knowledge Quizzes

In this research, quiz grades were the primary measurement of content knowledge. Students take two quizzes in the course that were designed to measure their content knowledge based on the course learning objectives.

Procedure

Students enrolled in the course (ME 151) in the spring of 2009 were given the self efficacy survey during class 4 times throughout the semester. The CCTST was offered once online at the end of the semester. Students were asked to take the CCTST, but it was not required in order to follow guidelines set by the Institutional Review Board. Students provided approximately 7 writing samples in ME 151 that were due after the completion of each mini design project. Self efficacy scores, critical thinking scores, cognitive development levels, quiz grades, and overall grades were compared using ANOVA and Pearson's correlation coefficient in SPSS (SPSS Inc, Chicago, Illinois) for those students who participated in self efficacy and critical thinking tests.

Results and Discussion

Since this project is a work-in-progress, not all of the data has been processed. Specifically, the cognitive development essays have not been coded yet. Nonetheless, results for the remaining three categories (critical thinking, self efficacy, and grades) are presented and have yielded intriguing results.

Table 1: Mean and standard deviation for the CCTST scores, self efficacy scores, and course grades.

2005	Average	Stn Dev
Final Grade	87.80	8.43
Quiz 2	47.50	17.43
Quiz 1	56.60	22.72
2006		
Final Grade	86.72	8.97
Quiz 2	74.22	19.69
Quiz 1	58.97	14.40
2007		
Final Grade	85.30	7.75
Quiz 2	71.08	15.35
Quiz 1	71.93	17.83
2008		
Final Grade	84.96	11.65
Quiz 2	68.26	19.94
Quiz 1	71.93	18.81
2009		
Final Grade	88.86	5.39
Quiz 2	77.92	19.14
Quiz 1	76.85	18.18
Crit. Think.	18.653	5.288
Self Eff. Ave.	76.79	19.63

Table 1 shows descriptive statistics for the CCTST results (2009), self-efficacy scores (2009), and quiz and course grades (2005 through 2009). The small difference in the averages of the course grades evaluated between 2005 and 2009 are not statistically significant and the standard deviations are very close indicating that the grades do not vary much. This is predictable since the course grades are curved at the end of the semester.

The CCTST was given once in 2009 to students enrolled in ME 151 at the end of the semester. The average score of on the CCTST was 18.653 and a standard deviation of 5.288. The national average on the CCTST is 16.801 with a standard deviation of 5.062. These scores were drawn from a population of a 2,677 four-year college students, of which 40% were first year students, 20% sophomore/junior level students, and 40% seniors level students [16]. Demographics and majors were not listed for these students so a direct comparison cannot be drawn, however the students enrolled in ME 151 did perform slightly better than those from the normal population.

In order to test for a statistically significant difference between the quiz grades over the five year period, the authors performed an ANOVA which compared quiz 1 and quiz 2 grades between 2005 and 2009. Since the ANOVA indicated significant results, Tukey's test was used for post hoc analysis to indicate which years had significantly different quiz grades. Tables 2 and 3 show the results of Tukey's post hoc test for quizzes 1 and 2. Quiz grades vary significantly if the significance level is less than or equal to 0.05.

According to the results shown in Table 2, quiz 1 averages are significant between 2005 and 2006 when compared with 2007, 2008, 2009. There is not a significant difference in scores between 2005 and 2006 or 2008 and 2009. Many changes were made to the ME 151 course to increase content knowledge between 2006 and 2008, so it makes sense that students would have higher content knowledge. Changes included scaffolding the curriculum, online video tutorials, use of a pseudo-code online learning module, use of a concept inventory, and use of projects with real world context.

Table 2 shows the mean difference (I-J) between quiz 1 scores. Statistically significant differences (level is less than or equal to 0.05) are shown in bold *italic* font.

Quiz 1	Year (J)			
Year (I)	2006	2007	2008	2009
2005	***-2.37***	***-15.33***	***-15.32***	***-20.25***
2006		***-12.96***	***-12.95***	***-17.88***
2007			0.01	-4.92
2008				-4.92

Table 3 shows the results of Tukey's post hoc test on quiz 2 grades between 2005 and 2009. Significant changes to quiz averages exist between 2005 and every other year as well as a significant change between 2008 and 2009. 2005 was the first year that quiz 2 was administered and since the class scored an average of 47.5, instructors determined that the exam was too difficult. The exam was changed in 2006 to be simpler and so the average grades increased significantly. The significant change between 2008 and 2009 can be attributed to the fact that pseudo-code, which is heavily weighted in quiz 2, was emphasized throughout the semester rather than just at the end of the semester.

Table 3 shows the mean difference (I-J) between quiz 2 scores. Statistically significant differences (level is less than or equal to 0.05) are shown in bold *italic* font.

Quiz 2	Year (J)			
Year (I)	2006	2007	2008	2009
2005	***-26.71***	***-23.57***	***-20.75***	***-30.42***
2006		*3.13*	*5.95*	*-3.71*
2007			2.82	-6.85
2008				-6.85

Table 4 shows the results of the self efficacy surveys were given to students in the course four times over the course of the semester. The results of the survey are difficult to interpret because this is the first time these particular surveys have been administered; however there is statistically significant improvement to the average scores between the first and last surveys, t (38) =-6.777, p =.000 (the notation used in this paper follows the standard format for reporting statistical results [17]). The average score increased between first and last survey by 6.8 points on a

100 point scale. This is a predictable result since the survey asks students questions that are based on course objectives. As they progress through the semester, their knowledge of the course objectives should increase.

Table 4 the results from the self efficacy tests given in 2009.

Self Efficacy 1	Average	Stn Dev
Confidence	78.11	11.51
Value	82.57	13.98
Success	80.43	11.54
Anxiety	60.37	28.12
1-Total	74.97	14.88
Self Efficacy 4		
Confidence	92.03	8.30
Value	90.39	12.57
Success	91.78	8.54
Anxiety	67.07	36.27
4-Total	85.22	14.73

Figure 2 shows a plot of critical thinking scores versus self-efficacy scores. SPSS statistical software was employed to determine if there was a correlation between critical thinking scores and self-efficacy scores. Using Pearson's correlation test, it was determined that critical thinking and self-efficacy are positively correlated. Using a 2-tailed test on 40 subjects, the correlation was significant at the $p=0.05$ level, $r(40)=.402$, $p<.05$, meaning that high critical thinking scores are associated with high self efficacy and vice versa.

The correlation between critical thinking and self efficacy shown in figure 2 is important because it suggests that higher self-efficacy is linked to better perfomance on critical thinking tests Although the scores are correlated, the authors cannot prove that there is a causal relationship between critical thinking and self efficacy. Despite the lack of evidence indicating that increasing self efficacy will directly increase critical thinking, professors may find it worthwhile to foster self efficacy in their students in order to help them be better students.

Figure 2 also shows that a small number of students had low self-efficacy and above average critical thinking scores. The authors looked at the breakdown of self efficacy scores for these subjects and found that they have low confidence in the objectives as well as a low ability to perform the objectives although they believe they are important to learn. This group also had high levels of anxiety about the objectives. The authors looked closer at these students and found that the majority of them are women. Only one female in the study was found to have high self efficacy. This could be a contribution as to why is it difficult to recruit and retain women in the Mechanical Engineering department. These women have high critical thinking skills, which suggests that they will do well in engineering, but they lack confidence in their ability to perform well in engineering classes. This lack of confidence could be the reason that they do not stay in the department. Since women are a minority group in engineering, they need to have a strong sense of self efficacy in order to compete with others in the department. The authors believe that by fostering self efficacy in the women enrolled in engineering classes, more women will graduate from the program.

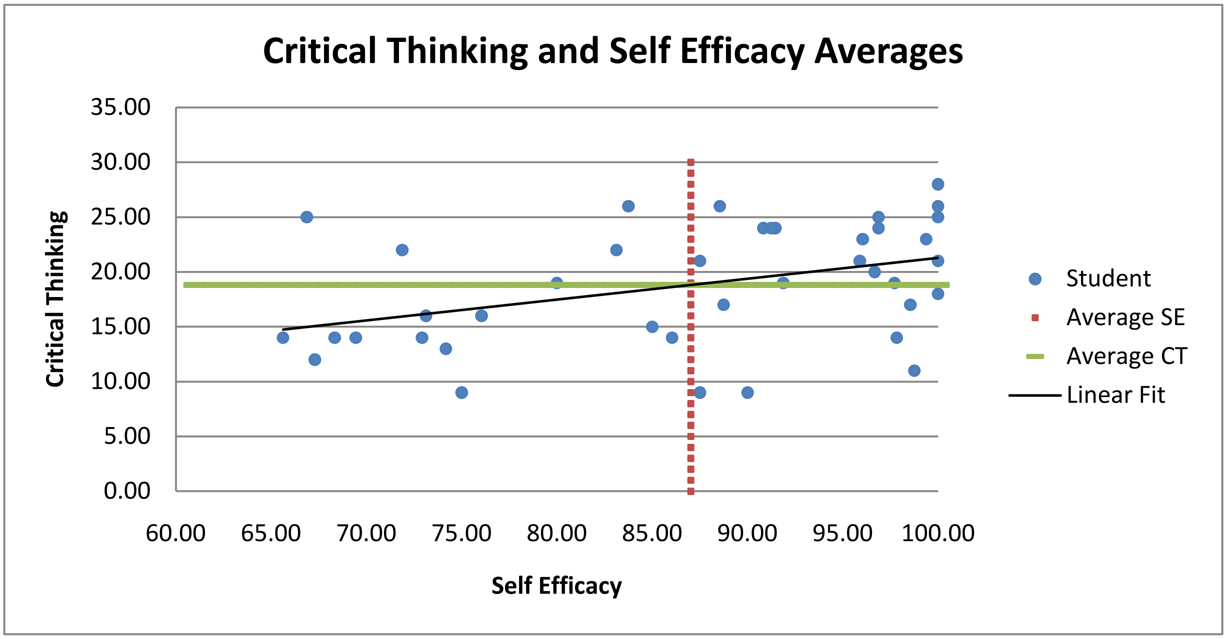


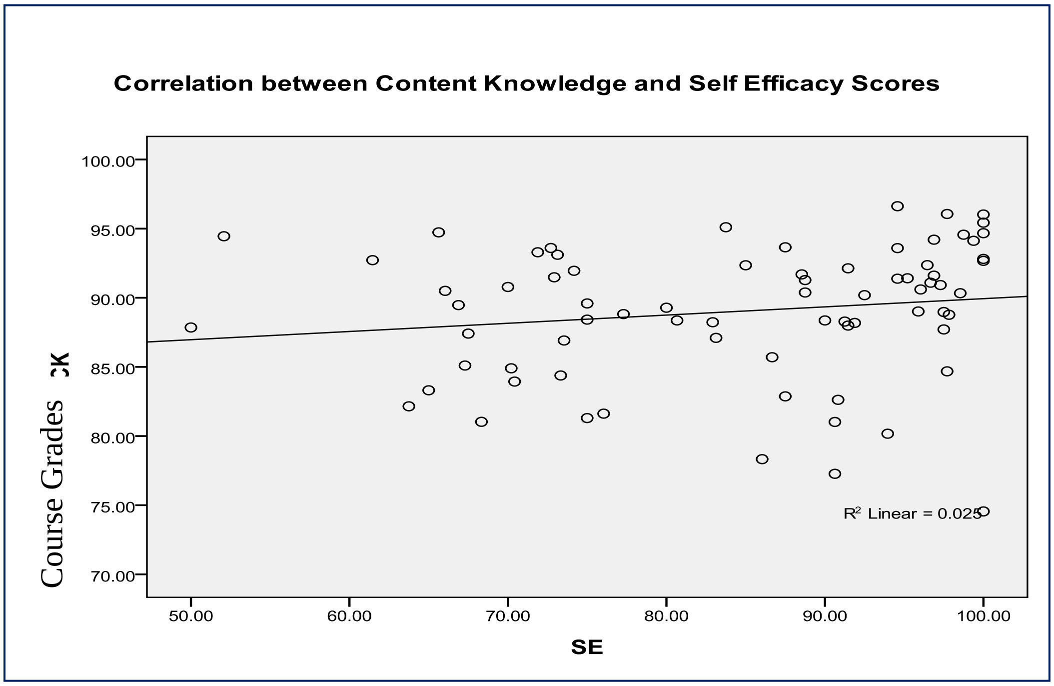
Figure 2: Scatter plot which shows the correlation between CCTST score and self efficacy results. Pearson's test results show a statistically significant positive correlation. Graph also shows the average self efficacy and critical thinking score, which are 86.3.

Opposing the subjects with high critical thinking skills and low efficacy are a small group of subjects with high self effiacy and low critical thinking level. Researchers scrutinized their self efficacy scores and found that they mostly gave the same response to each question indicating that they may not have answered the survey truthfully.

Figures 3 and 4 are plots of final grades versus critical thinking and self-efficacy scores respectively. Pearson's correlation test was also used to determine if critical thinking and self efficacy are associated with the final course grades students earned. No statistically significant correlations between either self efficacy and course grades or critical thinking and course grades were found.

Despite the correlation between self-efficacy and critical thinking, neither of these is correlated with the subjects' course grades. This is expected as course grades are often inflated or curved and not really a true measure of a student's ability. Based on the idea that the quality of a student can be determined by self efficacy, critical thinking, cognitive level, and content knowledge, researchers believe that course grades are not a good indicator of quality since neither self efficacy nor critical thinking scores correlate with grades.

Figure 3 Scatter plot relating course grades (CK) to self efficacy (SE) scores. There is not a statistically significant correlation between them.



Critical Thinking

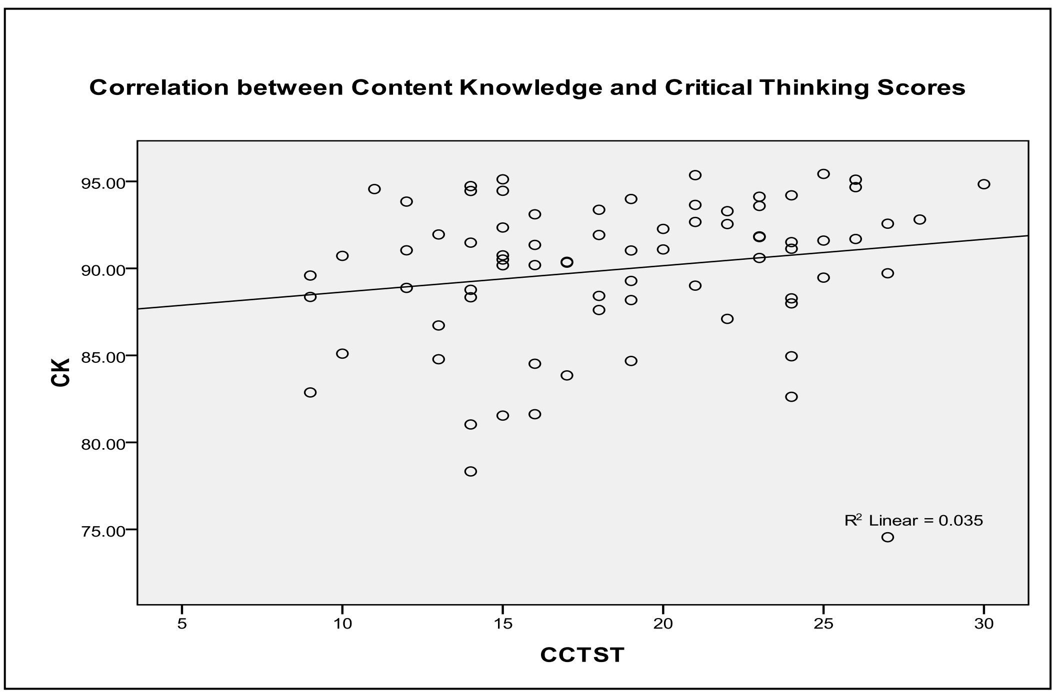


Figure 4 Scatter plot relating course grades (CK) to critical thinking (CCTST) scores. There is not a statistically significant correlation between them.

In addition to looking at the correlation between self efficacy scores, critical thinking scores, and course grades; SPSS was used to run a one way ANOVA to test for the difference in mean scores for self efficacy, critical thinking, and course grades using each student's self-reported expected course grade as a grouping variable. Expected course grade has a statistically significant correlation with critical thinking score (F (1, 73) =5.246, p=.025), however it does not have a statistically significant correlation with self efficacy (F (1, 38) =3.237, p=.08). This result is surprising since expecting a grade seems like it should be linked to self efficacy.

Limitations

There are some limitations to this study including the validity of the self efficacy tests and a limited number of subjects. Although the self efficacy tests were constructed based on Bandura's guidelines, this is the first time they have been used in a study. Ideally, there would be a standard self efficacy test to verify the results, but that violates the nature of testing self efficacy because it would need to be general. Since self efficacy tests need to be very subject specific to what is being tested, it is difficult to validate a test.

Conclusion

Based on the data collected, several major conclusions can be drawn:

- It was found that critical thinking and self efficacy scores are positively correlated with each other, but neither is correlated with the student's course grade.
- Students who stated that they believed they would earn an 'A' in the first year course performed significantly better in critical thinking.
- Critical thinking and self efficacy scores did not have a correlation with overall course grades, which suggests that course grades may not be the best method of defining the quality of a student.
- The vast majority of female participants exhibited low self efficacy scores, which may have major implications for retention.

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Understanding the Correlation Between Goal Orientation and Self-Efficacy for Learning and Performance in an Engineering Design Activity in Grades 9-12

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Abstract

This study was conducted to evaluate the relationship between students' goal orientation and self-efficacy for learning and performance while engaged in an engineering design activity in grades 9-12. Goal orientation includes students' intrinsic (IGO) and extrinsic (EGO) goal orientations. Self-efficacy for learning and performance (SELP) is a strong belief about the student's ability and confidence to perform the task.

A total of 113 students participated in the study. These students participated in five schools that implement Project Lead the Way curriculum in three states. After having completed their design project, each student was asked to complete a modified version of the Motivated Strategies for Learning Questionnaire (MSLQ) survey instrument which evaluated their IGO, EGO, and SELP. Several correlation tests were conducted to evaluate how students' IGO, EGO, and SELP impacted their work on an engineering design. The results show that there was a significant correlation between students' IGO and EGO, IGO and SELP, and EGO and SELP. The results also indicated a stronger correlation coefficient between IGO and SELP than between EGO and SELP.

Introduction

Many scholars and educators argue that one of the reasons for the limited number of students interested in engineering education is because of their lack of sufficient science and mathematics skills. Various efforts, such as inviting students to participate in engineering design competitions have been attempted to encourage high school students to enroll in engineering school; however, these efforts have been less than successful. Another avenue worth exploring is to seek an understanding of how students perceive engineering. Few studies have been conducted to investigate the issue from the perspective of the students' perceptions of engineering activities.

As engineering design activities are predominant in most K-12 curricular and professional development programs,[1] understanding students' motivation in engineering design activities is critical. Is the motivation to learn science and mathematics the main reason for the shortage, or are there other factors such as insufficient analytical skills that demotivate students in engineering design activities? Although there may be numerous factors that contribute to the lack of motivation to study engineering, understanding the connection between students' goals orientation and their confidence in their abilities to perform should positively contribute to knowledge building in the field of engineering and technology education, particularly at the precollege level.

The focus of this study is to answer one broad question: Is there a significant correlation between students' goal orientation (GO) and their self-efficacy for learning and performance (SELP)? In this study, students' goal orientation was measured through constructs such as intrinsic and extrinsic goal orientations. Students' self-efficacy for learning and performance was used to indicate students' self-efficacy and expectancy for success. Three specific research questions were constructed to guide this study. While engaged in an engineering design task, was there any significant correlation between students':

1. goal orientation (GO) and self-efficacy for learning and performance (SELP),
2. intrinsic goal orientation (IGO) and self-efficacy for learning and performance (SELP), or
3. extrinsic goal orientation (EGO) and self-efficacy for learning and performance (SELP)?

Relevant Literature

Insofar as this study is concerned, motivation refers to a drive that stimulates students to achieve their objectives (e.g., academic success). Motivation is exhibited by goal-oriented behavior and reflects "the willingness of the students to exert high levels of effort toward achieving goals."[2] Motivation consists of several constructs, including goal orientation, self-efficacy, task value, and control of learning beliefs, all of which have been widely discussed insofar as their interrelationships and effects on academic performance. This paper will address the relationship between students' goal orientation and self-efficacy in engineering design contexts.

Goal Orientation

Goal orientation is defined as beliefs that induce one to approach, engage in, and respond to tasks in different ways.[3] There are two general categories of goal orientation: mastery goal orientation, where students focus on mastery and learning of the material, and performance goal orientation, where students are concerned about demonstrating their abilities and performance compared to others.[4] In general, mastery goal orientation is associated with an inclination for challenging tasks, an intrinsic interest in learning itself, and positive motivational beliefs such as high self-efficacy. On the other hand, performance goal orientation is usually associated with seeking extrinsic rewards, such as grades and evaluation by others rather than an intrinsic interest in learning.[3,5]

Performance goal orientation can be further divided into performance-approach, where students strive to achieve a goal and demonstrate their abilities, and performance-avoidance, where students' major concern is to avoid failure and hide their lack of abilities.[6] However, according to other researchers,[7] goal orientation can be categorized into intrinsic and extrinsic. Intrinsic goal orientation involves the extent to which students perceive themselves as engaging in a task for reasons such as challenge, curiosity, and mastery; extrinsic goal orientation deals with the degree to which students perceive themselves as engaging in a task due to grades, rewards, performance, evaluation by others, and competition.[8] Students with intrinsic goals are inclined to exert more effort and are more likely to complete difficult tasks consistently than those with extrinsic goals.[9,10,11,12] Although a lack of agreement exists in the literature about the categories of goal orientation, on the basis of literature review and the definitions above, we consider that mastery goal orientation is analogous to intrinsic goal orientation in that they share some common constructs. To some degree, performance goal orientation is similar to extrinsic goal orientation.

Self-Efficacy for Learning and Performance

Self-efficacy refers to judgments about one's abilities to succeed in a given task.[13] It applies to a variety of contexts and is a good predictor of performance and behavior.[14,15] Numerous studies have suggested that strong self-efficacy beliefs are more likely to stimulate the exertion of greater efforts to overcome a challenge,[16,17,18,19] while weak self-efficacy beliefs tend to reduce people's efforts or even enable them to quit.[2] Self-efficacy beliefs influence behavior and motivation in several ways: They determine the degree of difficulties of the goals people set for themselves; how much effort they exert; how persistent they are when confronted with difficulties; and their resilience to failures.[2]

Method

Participants

One hundred and twenty-three students from five high schools in three different states participated in the study. A total of 113 students completed valid questionnaires. These schools implement Project Lead the Way (PLTW) curriculum, which provides middle- and high school students with opportunities for hands-on, rigorous, and preliminary courses involved in engineering or biomedical sciences. The reason why we chose schools that implement PLTW curriculum is twofold. First, student participants from those five schools would work on the same projects that have identical requirements and level of difficulty. Second, the teachers who deliver the classes across those five schools have received the same training on engineering design activities of PLTW. As a consequence, we assumed that the variation of student motivation due to instruction can be minimized because of similar instruction for selected engineering design activities and that results of the study on students' motivation when engaging in different engineering design activities are comparable.

These students participated in a Principle of Engineering class that required them to explore technology systems and manufacturing processes, and address the social and political consequences of technological change through a combination of activities-, project-, and problem-based learning. These students were required to engage in several engineering design activities (e.g., marble-sorter or bridge design).

Measures

This study utilized a modified version of the Motivated Strategies for Learning Questionnaire (MSLQ) survey instrument. The MSLQ is a self-reporting instrument developed by Pintrich, Smith, Garcia, and McKeachie[8] to assess college students' motivational orientations and their use of different learning strategies for a college course. The adopted items were modified by substituting any word describing *learning* with *engineering design activity*. This enables students to think about their design project while reading each statement in the survey. The wording became an essential factor in modifying the instruments because students may distinguish between their capabilities for dealing with two or more characteristically different topics or problems within the same measurement specificity.[20]

Although the MSLQ is designed for a college course, the researchers chose this instrument for three reasons: (1) This is the only instrument available that measures motivation with the value and expectancy components; (2) This instrument has been widely used in educational research in college and lower-level education courses; (3) Because the course in which the study participants enrolled (i.e. Principle of Engineering) is college credit equivalent, it was expected that statements in this survey would be understood by sophomore and junior high school students. Validation of the MSLQ and the subscale correlations with final grades were significant, demonstrating predictive validity. Confirmatory factor analyses tested how closely the input correlations could be reproduced given the constraints that specific items fall on. All 31 of the motivation items were tested to see how well they fit the latent factors. The Cronbach's alpha coefficients were robust, ranging from .52 to .93. Lambda-ksi estimates of the MSLQ, which are analogous to factor loadings in an exploratory factor analysis, indicated well-defined latent constructs.

Only three motivational scales (i.e., 16 items) were used in this study. First, the instrument was composed of statements that measured the student's perception of the reason he or she engaged in the learning task, an IGO (alpha = 0.74). Second, statements measured the degree to which the student perceived him or herself to participate in the task for extrinsic reasons, an EGO (alpha = 0.62). Third, statements were present that measured each student's expectation to perform the task well and to be self-efficient, a SELP (alpha = 0.93). Students rated themselves on a 7-point Likert scale, from "not at all true of me" (a score of 1) to "very true of me" (a score of 7).

Data Collection and Analysis

After completing the design project, students were asked to complete an MSLQ survey instrument. Pearson correlation tests were conducted to find any correlation between the goal orientation and the self-efficacy for learning and performance components (to answer research question 1). Similar correlation tests were also conducted to evaluate any correlation between each of the value components and SELP (to answer research questions 2 and 3).

Results

Correlations between students' IGO, EGO, and SELP

To determine the correlation between students' perception of the value of their design task and self-efficacy for learning and performance, several Pearson correlation tests were conducted. The statistical results (Table 1 and 2) show that:

1. There is a significant correlation between students' GO and SELP, r (113) = .720, $p < .01$.
2. There is a significant correlation between students' IGO and SELP, r (113) = .804, $p < .01$.
3. There is a significant correlation between students' EGO and SELP, r (113) = .362, $p < .01$.

It is clear from the statistical tests that students' goal orientation (including all IGO and EGO components) and SELP constructs are correlated to each other during the engineering design. The correlation factor (r) between students' IGO and SELP is much stronger than similar measures between students' EGO and SELP. Because the data were collected from two pools of students working on two different design tasks (i.e., bridge and marble sorter designs), further correlation tests were conducted to determine if significant correlations also occurred among students working on the same design task. From further tests it was found that significant correlations existed between IGO and SELP, and between EGO and SELP in each pool of students working on marble sorter or bridge designs (Table 3 and 4).

A simple regression test was also conducted to determine the relative importance of the contribution of IGO and EGO towards SELP. The results of the analysis revealed that IGO was a highly significant predictor of SELP (β= .779, p = .000). EGO was not a significant predictor of SELP (β= .065, p = .288). The IGO and EGO constituted about 64 percent of students' SELP.

Table 1. Correlation between GO and SELP

		SELP
GO	Pearson Correlation	.720**
	Sig. (2-tailed)	.000
	N	113

** Correlation is significant at the 0.01 level (2-tailed)

Table 2. Correlation between IGO, EGO, and SELP

		IGO	EGO
SELP	Pearson Correlation	.804**	.362**
	Sig. (2-tailed)	.000	.000
	N	113	113

** Correlation is significant at the 0.01 level (2-tailed)

Table 3. Correlation between IGO, EGO, and SELP (Marble Sorter Design)

		IGO	EGO
SELP	Pearson Correlation	.764**	.381**
	Sig. (2-tailed)	.000	.002
	N	66	66

** Correlation is significant at the 0.01 level (2-tailed)

Table 4. Correlation between IGO, EGO, and SELP (Bridge Design)

		IGO	EGO
SELP	Pearson Correlation	.796**	.306**
	Sig. (2-tailed)	.000	.036
	N	47	47

** Correlation is significant at the 0.01 level (2-tailed)

Discussion

Pintrich et al.[8] argued that students' self-efficacy for learning and performance is part of their expectancy for success. Thus, a significant correlation between students' goal orientation and self-efficacy for learning and performance found in this study indicates a significant relationship between students' interest in the design activities and their expectancy and confidence in completing the design task successfully.

A much higher correlation coefficient existed between IGO and SELP (i.e., $r = 8.04$) than between EGO and SELP (i.e., $r = 362$), implying a more dominant role of intrinsic motivation in the increase of students' expectancy for success. This result conforms to high beta value (i.e., $\beta = .779$) in the regression test results. Many studies have suggested that self-efficacy and intrinsic goal orientation are positively correlated to academic performance.[8,21,22,23,24,25] This suggests that students with high self-belief in their effectiveness or confidence are more likely to perform better academically. According to Schunk[26], when students see themselves as effective learners, they are more highly motivated, work harder on learning tasks, expend more effort, and display more self-regulatory behaviors. The level of self-efficacy, therefore, may be related to students' intrinsic motivation to persist in carrying out a learning task and thereby, affect their ability to develop problem-solving skills.

The results of this study may have some implications in engineering and technology education in grades 9-12. A stronger correlation coefficient found between students' IGO and SELP should be recognized as an important factor in developing engineering design curricula. The teachers may want to rethink about their design instructions and evaluation to boost students' intrinsic motivation. Engineering and technology teachers may want to develop the design tasks in several categories according to the level of difficulty of the tasks. When students perceive the design projects to be beyond their abilities, they may become discouraged, which may, in turn, lower their intrinsic motivation. For example, at the beginning of the engineering design, lower levels of task difficulty will enable students to be involved in the design activities more easily. However, with the progress of the design activities, the level of difficulty should be increased gradually so that students will be motivated to engage in the more challenging tasks and stages. The level of difficulty for the engineering design activities as a whole should be within students' proximal development zone[27] in order to ensure mastery and satisfy students' expectancy for success. Teachers may offer more challenging tasks for extra points or rewards, which will stimulate interested students and increase their intrinsic and extrinsic motivation.

Students' appraisal of challenge, task absorption, self-determination, and a feeling of autonomy are essential elements in intrinsic motivation.[28] Performance goals, on the other hand, are thought to increase evaluative pressure and anxiety, which may work against intrinsic motivation.[29] Three contextual factors: task design, distribution of authority, and evaluation of student practices may affect students' intrinsic and extrinsic goal orientation.[3,30] Task design refers to organizing the patterns of learning activities. Students may be encouraged to focus less on performance and more on learning. Distribution of authority refers to how much opportunity students have to determine their own learning process.[3] When students are allowed to make decisions, their interest in learning is likely to increase. The third factor refers to the basis for student evaluation. When evaluation is based on self-referenced information, students develop learning goals. However, when evaluation information is based on normative standards and social comparison, students will be more likely to focus on performance goals.[30] Teachers should not only focus on students' end results of the engineering design activities, but also on evaluating student progress at different design stages during the design activity. Creating a discussion forum where students and teacher can discuss real-life applications of their design tasks may also improve students' motivation.

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