Using Tablet PCs to Enhance Student Performance in an Introductory Circuits Course

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Abstract

Tablet PCs have the potential to change the dynamics of classroom interaction through wireless communication coupled with pen-based computing technology that is suited for analyzing and solving engineering problems. This study focuses on how Tablet PCs and wireless technology can be used during classroom instruction to create an Interactive Learning Network (ILN) that is designed to enhance the instructor’s ability to solicit active participation from all students during lectures, to conduct immediate and meaningful assessment of student learning, and to provide needed real-time feedback and assistance to maximize student learning. This interactive classroom environment is created using wireless Tablet PCs and a software application, NetSupport School. Results from two separate controlled studies of the implementation of this model of teaching and learning in sophomore-level Introductory Circuit Analysis course show a statistically significant positive impact on student performance. Additionally, results of student surveys show overwhelmingly positive student perception of the effects of this classroom environment on their learning experience. These results indicate that the interactive classroom environment developed using wireless Tablet PCs has the potential to be a more effective teaching pedagogy in problem-solving intensive courses compared to traditional instructor-centered teaching environments.

1. Introduction

Studies have long shown that the traditional instructor-centered lecture format is an ineffective learning environment, and that active participation, as well as interactive and collaborative teaching and learning methods, are more effective in various areas of science and engineering education including Chemistry\(^1\), Physics\(^2\), Engineering\(^3\), and Computer Science\(^4\). Various uses of technology have been found to be effective in enhancing the classroom experience to achieve more interactive and collaborative environments. These techniques include handheld wireless transmitters in Personal Response Systems (PRS)\(^5\), various forms of computer-mediated collaborative problem solving\(^6\), and the use of wireless Tablet PC technology\(^7,8\).

Tablet PCs are essentially laptop computers that have the added functionality of simulating paper and pencil by allowing the user to use a stylus and 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 solving and analyzing problems that require sketches, diagrams, and mathematical formulas. Combined with wireless networking technology, Tablet PCs have the potential to provide an ideal venue for applying previously proven collaborative teaching and learning techniques commonly used in smaller engineering laboratory and discussion sessions to a larger, more traditional lecture setting.

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Currently, the range of use of Tablet PCs in the classroom includes enhancing lecture presentations, digital ink and note taking, E-Books (books in electronic format) that allow hyperlinks and annotations, Tablet-PC-based in-class assessments, and Tablet-PC-based classroom collaboration systems such as the Classroom Presenter, and the Ubiquitous Presenter that can enhance student learning and engagement. As the use of Tablet PCs in the classroom grows, there is a growing need to understand how these various uses and applications can facilitate and enhance student learning.

This paper summarizes the results of a series of studies on how Tablet PCs and wireless technology can be used during classroom instruction to create a model that is highly interactive. In this paper, this model will be referred to as an Interactive Learning Network (ILN). The Interactive Learning Network (ILN) is designed to enhance the instructor’s ability to solicit active participation from all students during lectures, to conduct immediate and meaningful assessment of student learning, and to provide needed real-time feedback and assistance to maximize student learning. This interactive classroom environment is created using wirelessly networked Tablet PCs and a software application, NetSupport School, that allows various levels of interactions between the instructor and the students during lectures. In this model of instruction, less time is spent by the instructor delivering content through traditional instructor-centered lectures. The lectures focus on introducing new concepts and applying them to a few simple examples with more complex examples given as guided exercises. Students can access the instructor’s presentation and add their own annotations using Windows Journal or PowerPoint. Throughout the lecture, the NetSupport School software allows the instructor to quickly assess individual student understanding of concepts using instant student surveys. At the end of each lecture, more involved examples are introduced as exercises that students work on individually or in groups on their Tablet PCs using Windows Journal and/or other appropriate software (Excel, Matlab, MultiSIM, PSPICE, etc.). While students work on more challenging problems, the instructor has the capability to scan and monitor students' work from the instructor's tablet PC, and guide the students and assess their progress through NetSupport’s Survey mode using a series of short, previously prepared leading questions. Individual student questions are received through the Help Request feature, and individual assistance can be provided using the Monitor, Share, and Control features. The instructor is also able to effectively manage the various interactions through group chat, electronic whiteboard, and file transfer and distribution. The effectiveness of this model comes from the ability of the instructor to monitor and interact with individual students while they analyze problems on the computer using an input device that allows them to write and manipulate formulas, and make sketches and diagrams.

This paper will address the effects of these technology-enhanced interactions and collaborations on student performance, on student attitude towards the ILN model of instruction and the use of Tablet PCs in the classroom. Results of these studies will show that compared to courses taught with a traditional instructor-centered mode, the Interactive Learning Network can lead to: (1) better student performance in the courses where the technology is implemented, as indicated by better student grades on homework, quizzes, and tests compared to courses that do not use the technology, (2) better retention of prior prerequisite knowledge of basic concepts and their applications for students in the interactive class, and (3) positive attitude towards the use of the ILN model of instruction, and towards student use of Tablet PCs in the classroom.
2. Methodology

To determine the effects of the Tablet PC-enhanced interactive classroom on student learning in an Introductory Circuits Analysis course, two case studies each comparing an ILN-based class environment with a traditional instructor-centered class.

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 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 the traditional instructor-centered approach to teaching the class, the instructor presents new concepts, derives important equations related to the concepts, and then presents a collection of illustrative sample problems that are solved by the instructor in detail. Additional examples are given as in-class exercises, or assigned as homework problems. Periodic assessment of student learning is done in the form of quizzes and tests given during the duration of the semester. Success in this course using this approach has been limited, as Circuits has traditionally been an engineering course that has high attrition rates.

2.2. The Two Case Studies

To study the impact of the Interactive Learning Network model of instruction, two case studies were done: Study 1 involved comparing two Cañada College Circuits courses, the Spring 2006 class that used the ILN model, and the Spring 2005 class that used the traditional instructor-centered model. Study 2 involved comparing two Circuits courses from two different institutions in the Spring 2006 semester, a class at Cañada College that used the ILN model, and a class at San Francisco State University that used the traditional model.

Study 1: Cañada College Spring 2006 and Spring 2005. The Interactive Learning Network was first implemented in a Circuits class of 41 students at Cañada College in Spring 2006. Since Cañada College offers only one section of this class every Spring semester, a comparison group could not be established for the study. Instead, the performance of the Spring 2006 experimental group that used the ILN model was compared with that of the Spring 2005 Circuits class of 28 students. Similar homework, quizzes, and exams were given to both Circuits classes. An attitudinal survey was also administered at the end of the Spring 2006 semester to evaluate students’ opinion of the use of the ILN model and Tablet PCs in the classroom.
A comparison of student demographics for the two Circuits classes in this part of the study shows them to be very similar. The Spring 2006 class (ILN model) with 41 students, and the Spring 2005 (non-ILN) class started with 28 students. For both years, the majority of the students were male, and over 40% of the students were Mechanical Engineering majors. For both years, the ethnic distribution was diverse, with no majority ethnic group.

Study 2: Spring 2007 Circuits at Cañada College and San Francisco State University. For Spring 2007, two sections of Circuits courses were studied, one at Cañada College and one at San Francisco State University (SFSU), with both classes taught by the same instructor. As noted above, Cañada College offers only one section of Circuits every spring semester. To study the impact of the ILN model on student performance in the Circuits class at Cañada College, the Circuits class at San Francisco State University was selected to be the comparison group. In both courses, the instructor used a Tablet PC and a combination of PowerPoint and Windows Journal presentations to deliver lectures. The only major difference between the two classes was the student use of Tablet PCs and NetSupport School in the Cañada College class to create the Interactive Learning Network. Students in the Cañada class use Tablet PCs to take notes, to analyze and solve problems, and to interact with the instructor through NetSupport School software’s Instant Survey, Electronic Whiteboard, Chat and Help Request features.

The Circuits course at SFSU was a three-unit lecture course that met three hours a week for fifteen weeks, one week shorter than Cañada’s sixteen-week course. The first fifteen weeks of the Cañada class covered topics that were identical to SFSU’s topics. For the last week the Cañada class covered a topic that was not covered at SFSU and not included in any of the tests. The last homework set at Cañada was not included in the analysis and comparison of the performance of the two groups.

A comparison of the student demographics was done for the two groups of students for Study 2, with 16 students in the Cañada class, and 46 in SFSU. Both groups of students were ethnically diverse, with Hispanics as the biggest group at Cañada and Asians as the biggest at SFSU. At SFSU, 50% were Civil Engineering majors while the students at Cañada were more evenly distributed among the different majors (Civil, Computer, Electrical, and Mechanical). With respect to gender, the Cañada group had a slightly lower percentage of female students (12.5% vs. 17.4%).

Due to the inherent differences between the two groups of students in Study 2 (Cañada College being a community college, and SFSU being a university), a diagnostic test was given to the both groups to ascertain whether the students’ levels of preparation for the class were comparable. The diagnostic test consisted of fifteen multiple-choice questions measuring student knowledge of electric circuits concepts and their applications. These questions involved topics that were covered in the prerequisite Physics course. Results of this diagnostic test showed no statistically significant difference in the average and median scores of the two student groups.
2.3. Classroom Formats

Table 1 summarizes the similarities and differences in the classroom structure of the experimental and comparison groups of the two case studies. All four of the courses in the studies were taught by the same instructor. For the two experimental groups that used the ILN model, each student was given a Tablet PC to use during lectures, and interactivity during delivery of new topics was achieved using NetSupport’s Instant Survey and electronic whiteboard features that allow participation from all students. As previously described, most of the illustrative examples were given as exercises that students solved using the Tablet PCs while the instructor observed and guided their progress, and provided individual assistance through the NetSupport School software. For the comparison, non-ILN groups, the class structure was instructor-centered and non-interactive both during the introduction of new topics and solutions of illustrative examples.

The last row of Table 1 shows that for three of the four groups (2006 Cañada, 2007 Cañada, and 2007 SFSU) the instructor used the same method in generating and delivering lecture notes to the students. For these three groups, the instructor used a Tablet PC in combination with PowerPoint and Windows Journal to deliver class material. The Tablet PC replaced the blackboard and chalk (or whiteboard and pen), making it possible to have an electronic record of all the lecture notes prepared before and during class. An outline of the day’s lecture was usually prepared using a combination of PowerPoint and Windows Journal presentations. During lectures, the instructor added and saved handwritten annotations, sketches, derivations, illustrative problems, and problem solutions to the lecture notes that were then posted on the class website. This allowed subject material to be covered more efficiently and adjustment of the class agenda to be done more easily to accommodate student progress. For the non-ILN Spring 2005 Cañada group, the traditional chalk and blackboard was the main medium for generating and delivering lecture notes.

Table 1. Comparison of classroom formats for the experimental and comparison groups of Study 1 and Study 2.

<table>
<thead>
<tr>
<th>Classroom Format</th>
<th>Study 1</th>
<th>Study 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experimental Cañada 2006 (ILN)</td>
<td>Experimental Cañada 2007 (ILN)</td>
</tr>
<tr>
<td></td>
<td>Comparison Cañada 2005 (non-ILN)</td>
<td>Comparison SFSU 2007 (non-ILN)</td>
</tr>
<tr>
<td>Student Use Tablets</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Lecture Delivery of New Material</td>
<td>Interactive with Students using NetSupport</td>
<td>Interactive with Students using NetSupport</td>
</tr>
<tr>
<td>Presentation of Illustrative Sample Problems</td>
<td>Interactive with Students using NetSupport</td>
<td>Interactive with Students using NetSupport</td>
</tr>
<tr>
<td>Instructor Lecture Notes</td>
<td>Tablet PC</td>
<td>Tablet PC</td>
</tr>
</tbody>
</table>
2.4. Data Analysis

To measure the impact of the Interactive Learning Network on learning, the performance of the ILN and non-ILN groups for each of the two case studies were compared. For each case study, scores of the two groups of students on fifteen homework sets, four quizzes, four tests, and a final examination were compared. Identical homework problems were assigned from the textbook for the ILN and non-ILN groups within the same case study (Study 1 or Study 2). The average scores for the experimental and comparison groups were computed and independent Student t-tests were used to evaluate the statistical significance of the results.

For Study 2 consisting of Cañada 2007 and SFSU 2007 classes, an additional pre- and post-tests performance comparison was done. The Diagnostic Test given in the first week of the semester was again given a week before the final exam as the post test. The average scores for the experimental and comparison groups were computed and independent Student t-tests were used to evaluate the statistical significance of the results.

To determine students’ attitudes towards the use of Tablet PCs and the Interactive Learning Network model of class instruction, an attitudinal survey was given to the two experimental groups at the end of the semester. This survey has two parts: one on NetSupport School use and one on student use of Tablet PCs. It was designed to determine students’ perceptions of the impact of the ILN model on student learning and teaching effectiveness. Simple averages of student responses were computed to summarize the results.

3. Results

3.1. Study 1: Cañada College Spring 2006 and Spring 2005

In this section, performance of the two groups of students, Spring 2006 class with ILN format and the Spring 2005 class with a traditional format, will be compared. Additionally, results of the attitudinal survey on student perception of and satisfaction with the ILN model of instruction and the use of Tablet PCs will be presented.

Class performance comparison. A summary of the comparison of the performances of the two groups of Circuits students is shown in Table 2. Quiz Average is the average of four quizzes, Homework Average is the average of fifteen homework sets, and Test Average is the average of four tests. The last column of Table 2 is the difference between the average scores received by Spring 2006 students and Spring 2005 students. There is a significant difference between 2006 and 2005 results in Homework Average \( t(1,42) = 2.61, p < .01 \) and Quiz Average \( t(1,33) = 8.06, p < .001 \). Although the average of the four tests from the two groups have no statistically significant differences, two of the four have statistically significant differences – Test 3 \( t(1,54) = 2.05, p < .05 \) and Test 4 \( t(1,42) = 2.52, p < .05 \). Although the difference for the Final Exam is not statistically significant, the corresponding letter grade for the Final Exam was a “B” for the 2006 class, and a “C” for 2005 class.
Table 2. Comparison of Circuits student performance for Spring 2006 and Spring 2005.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Experimental</th>
<th>Comparison</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spring 2006 (ILN)</td>
<td>Spring 2005 (non-ILN)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N=41</td>
<td>N=28</td>
<td></td>
</tr>
<tr>
<td>Quiz Average</td>
<td>4.7 (out of 5)</td>
<td>3.4</td>
<td>1.3*</td>
</tr>
<tr>
<td>Homework Average</td>
<td>9.3 (out of 10)</td>
<td>8.6</td>
<td>0.7*</td>
</tr>
<tr>
<td>Test Average</td>
<td>76.6 (out of 100)</td>
<td>70.8</td>
<td>6.2</td>
</tr>
<tr>
<td>Final Exam</td>
<td>83.4 (out of 100)</td>
<td>77.8</td>
<td>5.6</td>
</tr>
</tbody>
</table>

*Note: The difference is statistically significant [p < .01].

Attitudinal survey on Tablet PC and NetSupport School: Spring 2006 only. Table 3 summarizes the results of the attitudinal survey administered in the Spring 2006 ILN class at the end of the semester. They show overwhelmingly positive attitudes towards the use of both NetSupport School software and Tablet PCs in the classroom. With respect to the use of NetSupport School, the “Help Request” feature was perceived most positively by students, with the control features (locking of student computers, Internet, and Applications controls) viewed the least positively. With respect to the use of Tablet PCs in the classroom, students viewed them as helpful in improving student performance and the instructor’s teaching efficiency, and creating a better learning environment.

Table 3. Summary of student opinions of NetSupport School and Tablet PC use in the classroom.

<table>
<thead>
<tr>
<th>Use of NetSupport School Software</th>
<th>Average Response (N=37)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response Scale: 4 – Strongly Agree, 3 – Agree, 2 – Disagree, 1 – Strongly Disagree, 0 – No Opinion.</td>
<td></td>
</tr>
<tr>
<td>NetSupport School program was helpful in improving my performance.</td>
<td>3.49</td>
</tr>
<tr>
<td>NetSupport improved the instructor’s teaching effectiveness.</td>
<td>3.64</td>
</tr>
<tr>
<td>The “Help Request” feature of NetSupport was useful to me.</td>
<td>3.68</td>
</tr>
<tr>
<td>My overall experience with NetSupport School has been positive.</td>
<td>3.67</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Use of Tablet PCs</th>
<th>Average Response (N=37)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response Scale: 4 – Strongly Agree, 3 – Agree, 2 – Disagree, 1 – Strongly Disagree, 0 – No Opinion.</td>
<td></td>
</tr>
<tr>
<td>Using the Tablet PCs in class helped me improve my performance.</td>
<td>3.58</td>
</tr>
<tr>
<td>Tablet PC use improved the instructor’s teaching effectiveness.</td>
<td>3.62</td>
</tr>
<tr>
<td>I would like to have Tablet PCs available for use in other courses.</td>
<td>3.60</td>
</tr>
<tr>
<td>My overall experience with Tablet PCs has been positive.</td>
<td>3.68</td>
</tr>
</tbody>
</table>
When asked the open-ended question what they like most about the NetSupport School software and the Tablet PCs, students responses included increased attentiveness and focus during lectures, real-time assessment of their knowledge through polling, immediate feedback on their work, increased one-on-one time with the instructor, ease of communication with instructor, and quick assistance when needed.

### 3.2 Study 2: Spring 2007 Circuits at Cañada College and San Francisco State University

The performance of the two groups of Circuits students, the ILN Cañada class and the SFSU class that use the standard instructor-centered approach will be compared in this section. Additionally, results of the survey on student engagement, expectations and confidence on mastery of course content will be presented.

**Class performance comparison.** Table 4 shows a comparison of the performance of the two groups of Spring 2007 Circuits students. Quiz Average is the average of four quizzes, Homework Average is the average of the fifteen homework sets, and Test Average is the average of four tests. The last column of Table 4 is the difference between the average scores received by Cañada students and SFSU students. The tabulated results also show higher scores for the Cañada (ILN) class in all categories. Differences between the scores are statistically significant for Quiz Average \( t(1,20) = 2.56, p < .05 \), Test Average \( t(1,35) = 2.11, p < .05 \) and Final Exam \( t(1,25) = 2.17, p < .05 \). The difference for the Homework Average is not statistically significant.

**Table 4.** Comparison of Spring 2007 Circuits student performance for the Cañada College class and the SFSU class.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Experimental Cañada (ILN) N=16</th>
<th>Comparison SFSU (non-ILN) N=46</th>
<th>Difference (Cañada – SFSU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quiz Average (out of 10)</td>
<td>8.3</td>
<td>7.2</td>
<td>1.1*</td>
</tr>
<tr>
<td>Homework Average (out of 10)</td>
<td>8.4</td>
<td>8.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Test Average (out of 100)</td>
<td>79.9</td>
<td>72.3</td>
<td>7.6*</td>
</tr>
<tr>
<td>Final Exam (out of 100)</td>
<td>86.4</td>
<td>79.4</td>
<td>7.0*</td>
</tr>
</tbody>
</table>

*Note: The difference is statistically significant \( p < .05 \).

**Pre- and Post-Tests.** Table 5 summarizes the results of the Pre- and Post-Tests. Although the Pre-Test scores of SFSU students are slightly higher than those of Cañada students, there is no statistically significant difference between the Average Pre-Test scores. The Post-Test Averages...
are significantly higher than the Pre-Test scores both at Cañada \( t(1,26) = 8.41, \ p < .001 \) and at SFSU \( t(1,79) = 7.50, \ p < .001 \). It should be noted that these tests were designed to be a diagnostic test that measures students’ knowledge of basic concepts of electrical circuits and their applications—topics that have been covered in the pre-requisite Physics course. Although the Circuits class increased the understanding and retention of knowledge in these topics for both groups of Study 2, the ILN group’s improvement is significantly better than that of the non-ILN group as indicated by the Post-Test results. The average Post-Test score is significantly higher for the Cañada group compared with the SFSU group \( t(1,29) = 3.97, \ p < .001 \).

Table 5. Summary of Pre- and Post-Test Results for Spring 2007 Circuits students for the Cañada College class and the SFSU class.

<table>
<thead>
<tr>
<th></th>
<th>Experimental Cañada (ILN) N=16</th>
<th>Comparison SFSU (non-ILN) N=46</th>
<th>Difference** (Cañada – SFSU)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post*</td>
<td>Pre</td>
</tr>
<tr>
<td>Average</td>
<td>5.5</td>
<td>12.3</td>
<td>5.7</td>
</tr>
<tr>
<td>Median</td>
<td>5</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>Stand Deviation</td>
<td>2.4</td>
<td>1.9</td>
<td>2.6</td>
</tr>
</tbody>
</table>

*Statistically significant difference \( p < .001 \) between Pre- and Post-Test average scores for both groups.

**No statistically significant difference between Canada and SFSU for Pre-Test average scores. Statistically significant difference \( p < .001 \) between Canada and SFSU for Post-Test average scores.

4. Summary And Conclusions

In assessing the impact of the Interactive Learning Network on student performance, it is important to determine how the different components of the model positively or negatively affected student learning. One of the most important components of the Interactive Learning Network teaching model is the immediate assessment of student learning and feedback on their performance. Research on learning theory has long shown that immediate feedback is an effective tool in increasing learning efficiency (Shute, 1994). For the case study at hand, the effect of immediate feedback can be seen in quiz and homework scores of the ILN classes. As a result of solving problems in class with the instructor’s guidance, students not only learned the material but gained confidence such that they were more successful in completing homework assignments and were better prepared for quizzes. Consequently, the completion and submission rates of homework assignments for the interactive classes were observed to be higher compared to the traditional instructor-centered classes (greater than 95% completion rate for both interactive groups, and less than 87% completion rate for the non-interactive groups). This difference maybe attributed to a tendency observed by the instructor for students in the non-interactive classes to delay studying class material until immediately before a test. For example,
during exam review sessions many of the questions raised by students in the non-interactive classes were similar to those raised by students in the interactive classes much earlier in the learning process.

Students in the interactive classes also attributed their improved performance to increased focus and attentiveness during class as a result of instructor’s survey questions, and the awareness that the instructor observed their progress. Furthermore, the “Help Request” feature of NetSupport was found useful by the students because it allowed them to ask specific questions anonymously. Another advantage of the electronically monitored interactive problem-solving sessions in class was that it enabled the instructor to identify common student misconceptions early in the learning process, thereby reducing student frustration when solving problems on their own. This early assessment of student learning sometimes presented a need for the instructor to adjust course material, making the class more dynamic and more responsive to student needs.

The Interactive Learning Network resulted in better student engagement as evidenced by higher attendance rates and more time spent on assigned tasks outside class time as indicated by an end-of-semester survey. Students also expressed positive attitudes towards the use of the ILN model of instruction, and towards student and instructor use of Tablet PCs in the classroom.

The use of Tablet PCs in the classroom further resulted in a number of distinct advantages that could have contributed to the improved performance of the ILN students. From the students’ point of view, the use of Tablet PCs during lectures provided enhanced note-taking ability, and improved their ability to organize class materials and allowed them to integrate hand-written notes and course materials. These features make a Tablet PC highly adaptable to individual students’ learning strategies (Ellis-Behnke et. al., 2003). From the instructor’s point of view, the use of PowerPoint and Windows Journal in presenting material coupled with the ability to incorporate hand-written annotations, sketches, mathematical equations, derivations, and animations increased teaching efficiency. These class notes, along with annotations generated during lectures, can easily be stored in electronic format and made available for student use outside class.

For the two case studies considered in this paper, there was a statistically significant improvement in performance for the interactive classes as compared to the traditional classes. The observed gains in the Quiz Average were statistically significant for both Study 1 and Study 2. The observed gain in the Homework Average was statistically significant for Study 1 but not for Study 2. The observed gains in the Test Average and Final Exam were statistically significant for Study 2, and not statistically significant for Study 1.

The results of the Pre- and Post-Tests of Study 2 indicate that although both the experimental and comparison groups significantly improved the Test scores during the semester, the gain for the ILN group was significantly higher than the non-ILN group. Since the questions given for the Tests were taken from topics previously covered in the pre-requisite Physics course, these results indicate that not only were there significant gains in the learning of new topics covered in the Circuits class, the ILN model of instruction also proved effective in retaining, understanding, and reinforcing previously learned topics.
In summary, the studies done here show that the interactive learning environment resulted in improvements in student performance compared to the traditional instructor-centered learning environment. These gains can be attributed to enhanced two-way student-instructor interactions, individualized and real-time assessment and feedback on student performance, increased student engagement, and enhanced and more efficient delivery of content.

The studies done here are limited and further studies are needed to be done in larger institutions using multiple sections of the same course to ensure that the experimental and comparison groups are comparable, thus increasing the reliability of the results. These studies should attempt to isolate the impact of the various components of the Interactive Learning Network on student learning to determine whether the immediate feedback through instant polling during lectures, the individual monitoring and assistance during problem-solving sessions, or the combination of both factors are responsible for improved student performance. Additionally, these studies should attempt to delineate the effects of Tablet PC use by the instructor from the effects brought about by enhanced interactivity due to student use of Tablet PCs in the classroom.

Similar studies should be done on courses with high attrition rates: courses that are traditional “bottle necks” for STEM students, and courses that are problem-solving intensive and requiring high levels of critical thinking. Finally, other software applications that promote interactivity in the classroom should be considered in conjunction with Tablet PC use.

5. Acknowledgements

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6. References


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Amelito Enriquez received his BS in Geodetic Engineering from the University of the Philippines at Diliman, his MS in Geodetic Science from the Ohio State University, and his PhD in Mechanical Engineering from the University of California, Irvine. His research interests include technology-enhanced instruction and increasing the representation of female, minority and other underrepresented groups in mathematics, science and engineering.
Photonics Research and Education at California Polytechnic State University

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Abstract

California Polytechnic State University is a major undergraduate teaching institute. We have a very active photonic teaching and research program in the Electrical Engineering (EE) department. In the recent years, the photonics group went through a big transition of the program with one professor retirement (founder of the program) and two new faculty members arriving. Our recent activities comprise following three major parts: 1) Expanded teaching laboratory, 2) Strong faculty/students research projects, and 3) Active SPIE student club. We are presenting the above three efforts in this paper.

1. Introduction

California Polytechnic State University (Cal Poly) has one of the nation's largest primarily undergraduate engineering colleges. The photonics program within the EE department began in 1985. Currently, there are two senior elective lecture courses and one graduate-level lecture in the photonics area. A 700 ft² fiber-optics laboratory was introduced in 1986. This laboratory serves dual purpose for undergraduate teaching (3 benches) and undergraduate/graduate research (1 bench). The Photonics laboratory has undergone a series of equipment and laboratory procedure improvements and since its inception. The 700 ft² room size limited teaching section size to 9 people and this made it one of the department’s most expensive laboratories to teach. The demand for the class has been high resulting in a large teaching demand to service the students. The laboratory underwent an expansion in 2008 to a double size room of 1400 ft² allowing 18 students per classroom section, with six undergraduate teaching benches and two undergraduate/graduate research benches. The high cost of equipment per bench/station has necessitated rotation of experiments to minimize capital equipment expenditures for the new lab. Fig. 1 is one corner of the photonic lab. It shows two teaching benches with students working on their experiment. Overall, the newly innovated photonic lab not only serves the teaching lab better, but it can also support more undergraduate/graduate student projects, such as senior project and master’s thesis, which are very important laboratory experience. Moreover, one recent focus of photonic lab has been university – industrial collaborative projects, which is addressed in the paper. Finally, the Cal Poly SPIE student club is very active in the past four years. It has been a companion technical and social activity source for students interested in the photonics field.
2. Innovative lecture and teaching laboratory

The Cal Poly Photonics faculty initiated an update our photonic courses three years ago focusing on EE403 Fiber Optic Communication and EE443 Fiber Optics Laboratory. In winter 2005, we adopted a new textbook for EE403 and added multimedia course material in the lecture. To match the new EE403 class, new EE443 lab experiments were required. The old lab experiments were:

- Experiment Prelim: Digitizing Oscilloscope (DSO)
- Experiment 1: Handling Fiber, Numerical Aperture
- Experiment 2: Attenuation, Splicing, OTDR
- Experiment 3: Single Mode Fiber, Source characteristics
- Experiment 4: Source, Coupling to Optical fiber
- Experiment 5: Bandwidth of an optical Fiber

These five laboratory experiments were primarily focused on the device-level experiments. For the lab expansion, a new emphasis on adding system-level experiments was made:

- **Experiment 5-NEW: Optical Link Experiment (added in Fall 2008)**
  The laser function generator instrument (1985 vintage) of the old Lab No.5 had multiple failures and the instruments are now unrepairable. Only one station out of the four duplicate sources was fully functional. The old experiment 5 was replaced with a modern fiber optic link source and receivers using SFP fiber optic transceivers. The new Lab 5 Optical Link Experiment shows students how to build a modern fiber optic digital link using standard optical transceivers. This experiment also preserves the old experimental goal of estimating the bandwidth of a 1 km multimode fiber spool.
• **Experiment 6: EDFA:** *(added in Fall 2007)*
Lab 6 EDFA was first designed and deployed in the EE443 lab in Fall of 2007. This lab teaches students about Erbium Doped Fiber Amplifiers (EDFA) and their applications. Erbium doped fiber amplifiers were only in the early research stage when the photonics lab was initially established at Cal Poly. This lab contains both EDFA system hardware characterization and Computer Aided Design (CAD) simulation of systems utilizing optical amplifiers. The CAD tool allows the students to explore a variety of EDFA architectures that would take too much time to build during a laboratory session.

• **Experiment 7: OPTSIM Preliminary Experiment** *(added in Fall 2008)*
Through this lab, the students are exposed to a CAD program that can simulate a wide range of fiber optic links. The simulation can be used to compare experimental results such as the link of experiment 5 or newer designs which are too time-consuming and expensive to build. Rsoft’s OptSim simulation tools have been our focus system simulation CAD tool for fiber optic links.[1]

• **Experiment 8: OPTSIM NRZ Optical System and OSNR Spectrum Chart** *(added in Fall 2008)*
Students use OptSim to calculate the Optical Signal-to-Noise Ratio (OSNR) and optical spectral content of a 10 Gb/s optical system with EDFA preamplifiers, mid-link amplifiers and booster amplifiers. The 10 Gb/s NRZ optical signal is launched into 3 spans of Dispersion-Shifted single mode fiber, each 50 Km in length. The fiber loss is recovered by 980-nm pumped EDFA before each span and after the third span. The optical signal is passed through a raised-cosine filter and detected by a sensitivity avalanche photodetector receiver. The electrical output of the receiver is passed through a Bessel filter to limit the bandwidth of the electrical receiver and maximize sensitivity. The student laboratory assignment includes optimization of the system signal to noise ratio.

• **Experiment 9 (optional) 4 Channel WDM**
The students design a simple 4-channel wavelength division multiplexing (WDM) system using the OptSim simulation tool. Since the hardware associated with a WDM system is very expensive system for a student teaching lab, the simulation illustrates key design concepts unique to WDM systems. The system design requirements are: Design a 4-channel WDM transmitter at 2.488 Gb/s with a NRZ modulation format and a p-i-n photodiode receiver. The four signals are pre-amplified by an EDFA booster and transmitted over a sequence of two Dispersion Shifted fiber spans of 100 km each. The fiber spans have opposite dispersion signs (D=+/− 2.16 ps/nm/km) resulting in ideal dispersion compensation at the middle of the simulated bandwidth. A second EDFA is used in the receiver section as a preamplifier.

This photonic lab expansion project was a joint effort of students, professors, EE technician staff, and the EE department leadership. The driving goal of the expansion was to serve the continued high demand for our photonics lecture/lab courses and minimize the number of laboratory sections to service this need. First, professors set up the lab expansion goal and topics. And we looked for both external and internal funding sources to implement our new laboratory exercise goals. Second, students were enlisted to help design and troubleshoot the new experiments under the guidance of professors as their senior projects for the past three years.
Finally, department allocated $60,000 of internal funding to complete the costs of doubling the teaching space allocation from 700 ft\(^2\) to 1400 ft\(^2\). This included the purchase of four new optical benches, equipment racks, computers and infrastructure changes. Test equipment donations from industry also helped to populate the expanded number of laboratory stations.

The original laboratory had three optical tables for teaching proposes. Each table allow a maximum 3 students to do one set of experiments. Therefore in each three-hour lab section, there were only maximum 9 students. We had to offer at least 4 lab sections each quarter to match each the EE403 lecture or EE418 lecture size. The large number of required lab sections was a driving force for the financial support of the EE department leadership group. The most straightforward approach might have been to purchase identical test and measurement solutions for the 3 new benches associated with the doubling of the photonics laboratory area. However, most of the older lab test and measurement equipment was 10 years old and it did not make sense to try and duplicate the old measurement station equipment. The cost of providing a complete section of next generation test and measurement for the three new optical benches was also too expensive to implement over a short period of time.

A compromise solution was reached. We capped enrollment at 2 lab sections each quarter with 18 students in each section. This contrasted to the earlier format of instead of 4 sections of 9 students with the smaller sized laboratory. The doubling of lab size from 700 ft\(^2\) to 1400 ft\(^2\) was accomplished by constructing a curtained opening between the original room RM 20-314 (original photonics laboratory) and the adjacent room RM 20-315 (old digital signal process DSP lab). The expanded lab area in room 20-315 now contains our new set of laboratory exercises 5 through 9. The original room utilizes the old laboratory experiments 1-4. We place six teaching benches with two set of experimental setups, as shown in the Fig. 2 below. The students will be in two groups (group A and group B) and switch experiments every two weeks.

The following objectives were achieved with the laboratory expansion and upgrade:

1. Increase enrollment from 9 to 18 students per laboratory section. It is estimated that the EE department’s $60k expansion cost will be repaid in less than 3 years by reducing teaching hour demands for the course.
2. For each experiment with large capital expense, equipment spares were put in place. Four duplicate equipment copies instead of six copies are needed for each experiment.
3. Compatibility was maintained with the existing experiments 1-4 and their associated equipment needs.
4. The new optical bench space is not fully occupied leading to the ability for future laboratory enhancements.
5. The added space gives a larger open area to facility lecture/lab capabilities in the same room.
6. An additional optical bench was dedicated to senior project activities and master’s thesis projects.

With department supports and approval, the expanded laboratory opened in the fall of 2008. A second undergraduate photonics lecture/laboratory course, EE458 is now being targeted for expansion to include 18 students per sections.
3. **Strong faculty/students research projects:**

With the photonic lab expansion project, the department also doubled its photonic research/project area in 2008. This will support more photonic faculty/student projects. The major projects are:

- **International research collaboration [2]**

  We established a long-term cross-three-campus international engineering education and research collaboration program among California Polytechnic State University (Cal Poly), USA, California State University, Long Beach (CSULB), and Peking University (PKU), Beijing, China on GaN light emitter research in the past four years. The research is focused on GaN laser diode topics for the first year. GaN Light emitting diode research was added during the second year and nanostructure grating simulation was emphasized on the third year. LED control circuit research is under development now in the fourth year. The effort has been supported by the Wang Faculty Fellowship through California State University international programs and other funding. Faculty members, Dr. Jin (Cal Poly) and Dr. Wang (CSU Long Beach), worked at PKU during the summer of 2006 to initiate a joint research project on GaN laser diodes. In the following years (2007 and 2008), they continued this effort with two summer visits and further extended the project to include research on GaN light emitting diodes, with funding from the US (Cal Poly) and China (“ChunHui” international scholar exchange program). A graduate student, Simeon Trieu, from Cal Poly also visited PKU in the summer of 2008 and is applying NSF EAPSI (applied in Dec 2008 and got initial acceptance letter from NSF) and other support to work in PKU in the summer of 2009. Cal Poly/CSULB graduate students are grouped with

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*Fig. 2 The layout of new experiment setup and new research benches in EE photonic lab.*
graduate students in Peking University and worked closely on mutually defined projects. The participating students obtain experience in transcontinental collaboration and gain an awareness of culture differences. Three journal papers and five conference papers on GaN research and education have been published by participating researchers since 2007. [2][4]-[10] A paper is accepted for conference presentation in April 2009. [11] Student comments from both continents confirm that they obtain better understanding about foreign cultures as a result of this activity. Student comments indicate they believe that this activity will be helpful for job prospects in multinational engineering firms. Currently plans include involvement of undergraduate students into this project in order to extend the education scope.

• Research Lab-Cal Poly collaboration
We also collaborate with Lawrence Livermore National Labs (LLNL). LLNL has offered a graduate study internship in conjunction with Cal Poly since 2004. Cal Poly faculty members identify prospective student candidates for the graduate internship. Dr. Agbo is the LLNL coordinator for Cal Poly. During the past three summers, Dr. Agbo also worked at LLNL as a Summer Faculty Scholar on an Ultra-Wideband (UWB) Communication project. An UWB system utilizes an enormous bandwidth, but because it operates at very low power levels comparable to the noise level. Because of the low spectral density of the modulation, it can overlay other channel plan allocations. Therefore, it requires no bandwidth assignment from the Federal Communications Commission.

• Industry sponsored projects
The EE photonic faculty is principle investigators of various industrial and/or government agency sponsored projects:

A partial list of Dr. Jin’s recent projects include “Simulation of the 633nm photodetector using Crosslight” funded by Agilent in 2008, “Modeling and testing of semiconductor lasers, cables, and photodiodes for interferometer measurement system applications” sponsored by Agilent Global Research Grant in 2006-2007, and “Investigation of photonic lattice based Gallium-Nitride light emitters” funded by the Office of Naval Research (via C3RP program). She also collaborated with several industrial companies, including Rsoft Design Inc and Crosslight Inc.

Dr. Derickson has cooperated with JDS Uniphase Corporation on tunable laser projects and published several papers on the topic. [12] [13] Fig. 3 is a Cal Poly graduate student presenting paper on microwave signal generation using self-heterodyning of a fast wavelength switching SG-DBR Laser in the SPIE International Symposium on BIOS 2009, SPIE Photonic West 2009 in January 2009 on the JDSU project. [13] In this paper, microwave signal generation using single-chip fast wavelength-tunable SG-DBR lasers is demonstrated. Microwave signals are established by a self-heterodyne technique. The laser frequency is square-wave modulated back and forth between two closely spaced wavelengths. These two wavelengths are made time coincident using a fiber Mach-Zehnder interferometer. The difference frequency is detected and amplified. Microwave signals up to 12 GHz have been measured by frequency modulating the phase section of the SG-DBR laser. Millimeter wave difference frequencies are easily available from the SG-DBR laser. Microwave signal spectral widths as narrow as 10 MHz have been achieved for low back mirror current inputs. Spectral width results as a function of device DC bias condition are presented. A high-speed wavelength switching SG-DBR package has been
Time resolved frequency step measurements have shown inherent thermal transients of approximately 200 ns upon wavelength switching. From the square wave switching profile, switching times of approximately 40 ns were achieved.

![Project Introduction](image)

**Fig. 3** A Cal Poly graduate student presenting paper on microwave signal generation using self-heterodyning of a fast wavelength switching SG-DBR Laser in the SPIE International Symposium on BIOS 2009, SPIE Photonic West 2009 in Jan 2009 on the JDSU project

4. **Active SPIE student clubs** [3]

A SPIE student club was formed in 1986 so that students who had an interest in photonics could have a common forum and bond together as an entity. Leading by Dr. Derickson, SPIE student club is very active in the past four years. Each year, SPIE also offers 2 major conference events that are within driving distance of Cal Poly. Photonics West is held in San Jose each January and the SPIE annual meeting is held in San Diego each August. Both of these events offer great opportunities for students to observe first-hand the diversity of the photonics field. SPIE offers student scholarships for travel to the conference. The students group meets bi-weekly and features guest speakers on a range of photonics related topics along with free pizza and soda. Several social events are also organized throughout the year. SPIE is a generous funding organization for student chapters. Students join the SPIE organization for $20 per year. The membership includes journal publications and a monthly news magazine. SPIE then donates operating funds back to the student chapter in proportion to the number of student members. SPIE offers student scholarship, activity grants and pays for guest speaker forum for its student chapters.

Another major focus of the SPIE student chapter each year is to provide a display at Cal Poly’s open house celebration. Annual crowds of over 10,000 people gather together on campus in April to see activities from the departments and student clubs. The entire event is student managed. This activity again helps form an identity for those students interested in the photonics field and offers new students, parents, and their siblings a chance to see photonics in a fun-filled hands-on display.
5. Conclusion

In summary, this paper described efforts to allow Cal Poly’s EE photonics program produce a more modern photonics education program to meet current education goals: modernize existing lab with low cost and compatibility with older labs; introduce an international educational element; project-based learning; team based learning; and photonics CAD-based learning.

Reference

Longitudinal Contact with Individual Students as a Route of Encouraging Self-Determination in Chemical Engineers

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Abstract

It is difficult to have contact with individual students over a sustained period of time due to constrained schedules and competing time demands. However, frequent contact with individuals over time allows advisors to build student strengths in self-determination while tailoring advice directly to changing interests.

The talk will highlight advising opportunities from outreach, through retention, continuing to graduation, and post graduate interactions that fit within student progress towards their individual careers. Appropriate advising content for a technically rigorous chemical engineering program will be used as examples of how to motivate students towards exploring options and making decisions that open new doors to professional development. The issue explored is that self-determination comes from inside the student and that confidence in personal evaluation is fostered through directed activities throughout students' time with us.

Objectives that readers should be able to meet will be:
• to have the ability to identify points of contact where longitudinal contact can be encouraged
• to have the knowledge of how to remove impediments to longitudinal advising through reconstruction of advising duties in larger programs with many staff members, or through directed contact with students in smaller departments
• To have the ability to link student possibilities to exploratory activities that lead to self-determination

Students in chemical engineering are generally very strong in academic abilities, but often have not been exposed to a breadth of activities and possibilities that enable them to construct their own paths. Sustained advising contact has led to strong statistically-based success of students who have progressed through our program with approximately 30% of our graduates entering top ten chemical engineering graduate programs, 100% student placement of graduates almost every year, and a host of university-based, state, and national awards going to our students.

Introduction

Most faculty appointments in the United States carry the expectation that there will be a balance among different work activities[1-4]. The typical assumed split on a time percentage basis is 40% on research, 40% on teaching, and 20% on service, although those percentages vary in reality[5]. One way of meeting service obligations is for faculty to take on the task of advising students in their disciplines[4, 6, 7]. Activities in the advising area provides service to many constituents, including to the students, to the department, to the profession, and to our
stakeholder companies, employers, and the general public. Students benefit directly from the close communication and exposure to ideas of an "expert" in the area of academic development. The department benefits directly by smoothing the progress of students through their programs while maintaining high standards and increasing statistical measures often used for evaluation of programs like retention, average student time to graduation, and student contact hours. The profession is improved by the production of students who are prepared to think rigorously about their own development and how to engage in lifelong learning. Stakeholder companies and employers benefit by a larger pool of graduates that may be more highly qualified than a student pool that had been unadvised. Finally, the general public benefits through the production of responsible citizens who contribute not only to the financial health of their local economies, but also through the goods and services provided by educated engineers.

While the benefits of advising were listed above, the purposes of advising are more focused on the students. Navigating engineering curricula is not easy for most students. There are many constraints placed on course offerings, timing of events, prerequisite courses needed for advancement, grade point needs, and other academic concerns. Students often struggle along the way when a situation occurs that moves them farther away from the norm of progress, and they can leave engineering or give up on higher education completely. Outside of the academic areas, students may need other institutional support to help them function well in the learning environment. These resources can be efficiently accessed after students are advised of their existence and how they can be taken advantage of. Examples of support students may make use of include tutoring help, psychological and counseling services, legal services, health care professionals, mediators, and many others. Getting the students the help they need when they need it enables them to stay focused on their coursework while managing their daily lives better.

There are many models for how student advising can be accomplished. One example commonly encountered by students could be called punctuated equilibrium. This is where students are required to meet with specific advising staff or faculty at certain gate-keeper events like the transition from being a pre-engineering major to being in a specific major, the transition from lower division (freshman/sophomore) status to upper division (junior/senior), or advancement to graduation through a formal degree check. Students may or may not ever meet with an advisor during other times during their academic career.

Another model for advising could be called a single pass through approach. This is one where there are designated advisors for each academic rank, for instance one or two advisors for freshman, one or two for sophomores, etc. In this approach, students have the opportunity to engage with at least four faculty during their time as students, giving them a broader access to more viewpoints and expertise. One problem with this approach is that it is inefficient. Faculty/advising staff must spend time evaluating where each student is before moving on to the actual advising when they meet with a new advisor each year. Additionally, the advice may be the same that students have heard previously but then discovered did not help them; this is inefficient for both faculty and students.

A third mode of advising students is the least formal and could be called "catch as catch can". Students moving through a program organized around this theme do not have specific advisors for any point in their academic progress so they may not be able to get the help they need. They
may not even know who to ask for help in constructing their class schedule for core courses, leading to disaffection and loss of motivation to continue.

A final method of advising students is almost continuous and could be called "longitudinal advising". One faculty/staff member is responsible for a student during their entire program of study at the university, leading to long term and sustained contact over time. Faculty in this model get to know the students well and can provide the most relevant advice as needed because they know the students' abilities, their weaknesses, and what works well for them. The intimate and close contact allows the faculty member to write much stronger and more specific letters of recommendation for students when they apply for positions, graduate school admission, or scholarships, as well. Students get to know one faculty member well and this can enable them to know the faculty more as a person than just an institutional representative. The strengths of longitudinal advising are enhanced when combined with situational leadership approaches[8] or developmental advising[9] approaches preferred by students[10].

This paper describes longitudinal advising of students, how it can be implemented through different contact points with students, and how it can lead to students being able to better control their own futures through self-determination. Motivating students is a strong focus, especially at critical points when many students may consider leaving engineering for other less challenging disciplines. The core set of skills that students must have upon graduation for success are then described, along with some subskills that may be conveyed for subdisciplines.

A Sample Department Where Longitudinal Advising Has been Implemented

A few comments will be made about the department and the local environment where longitudinal advising has been done to highlight some of the characteristics that enabled this approach to be successful. The academic achievements and professional accomplishments of the students over the recent pass will also be highlighted to show the outcomes of this advising approach.

The chemical engineering department in this work has 14 faculty. These faculty members oversee one B.S. program in chemical engineering and M.S. and Ph. D. programs in both chemical engineering and environmental engineering. About 6 faculty members teach the 14 core B.S. chemical engineering courses and it is the B.S. population that will be the focus of the rest of the discussion.

All faculty members in the department are engaged in both teaching and research and there are no adjunct faculty who teach courses. The involvement of all faculty in all aspects of the department leads to more interactions among students and faculty. The student class size is about 55 at the sophomore level and between 30 and 40 students at the upper division junior and senior levels.

Core discipline courses are restricted to being offered only once a year and are fairly evenly spread over a 6 semester series. The hierarchical nature of the core courses mean it is critically important for students to work with an advisor to ensure they stay on track; deviation from the prerequisite courses delays student graduation by a full year in almost every case. One feature of
the program and course hierarchy is that once students begin their sophomore year, they will be with those same peer students until graduation. This makes it easier for faculty to track student progress and to follow different cohorts.

The student population in the chemical engineering B.S. program is very strong academically while also being diverse. Roughly 50 percent of each graduating class is female, which can be compared to the rest of the college being 18% female. This difference between chemical engineering and the rest of engineering is similar to those of other programs. About 85 to 95% of each graduating class is composed of domestic students. Forty-eight percent of the students are enrolled in the Honors Program at the university, which is about 3 times higher than the general student population with an 18% involvement. Out of each graduating class of 30 to 40 students, there will be 2 or 3 National Merit Scholars. Approximately 75% of each graduating class has done research in a faculty lab before they graduate. The students in the program are arguably the best in the college and university.

Student excellence in academic pursuits is evident at the local and national levels. At the college level, a chemical engineering student has been named the top student in the college 90% of the time, even though there are 18 different programs who nominate students each semester. At the university level, there are 10 or 12 students honored each year for being Pillars of Excellence, as selected by the Honors College. Out of the past 22 awardees, four have been chemical engineers. Also at the university level, three students in the past 6 years have been named the top undergraduate researcher in an internal competition. At the national level, students have been very strong in competition with other top chemical engineers at American Institute of Chemical Engineers conferences. In the last eight years, three students have been named as the best undergraduate researcher in poster competitions. It should be noted that the three national research awardees were not the same students as the local award, highlighting the depth of undergraduate research involvement. One student in the recent past was named the best chemical engineer in the country by AIChe after placing first in the oral competition at the national conference. Finally, students compete strongly at national level for scholarships and other awards. Four students in the past two years have been named Tau Beta Pi fellows and one was named the best engineer in the country as that organization's laureate. There have been numerous Udall scholars, NSF fellows, and one Fulbright award winner in the last three years.

Students compete strongly for both graduate school admission and for full time employment. One third of our graduates have consistently gone on to graduate school with about 95% of them going to Ph. D. programs that are ranked in the top 10 or 20. Students have gone to graduate school for degrees in chemical, biochemical, biomedical, mechanical, and environmental engineering. Students have also gone on for advanced degrees in pharmacy, mathematics, law, and medicine. On the job front, all but 1 or 2 students each year will have accepted an employment offer or graduate school offer by the day of graduation. Typically, the students without offers were not pursuing options or had U.S. visa issues.

Part of the success of our students comes from their diverse outside interests and their strengths in them, which are fostered by faculty members through longitudinal advising. In the past three years, graduating seniors have been leaders in many areas. One student was a Division I athlete who placed sixth at the PAC 10 track championships in high jumping. Another student was
named the best collegiate pianist at the university and then in the state, beating out M.S. and Ph.D. piano performance majors. One student routinely placed first or second in the American Tae Kwon Do Association's international weapons and hand-to-hand combat competitions. The Tour de Tucson is a 109 mile bicycle race that takes place late in fall semester, typically during a round of exams right before Thanksgiving. Three students have completed this race in the past three years, one of whom has cerebral palsy. Six students in the past three years have completed a marathon during the school year, two have completed full triathlons, and one third of the class two years ago completed the Tucson Half-Marathon. Students from the department have founded Engineers Without Borders, the Boxing Club, the Marathon Club, and the Table Tennis Club. On top of these students, approximately 1 single parent graduates each year.

Longitudinal advising is one of the mechanisms that allows the students to develop into the strongest candidates for their future endeavors and to achieve the successes just described. In addition, longitudinal advising eliminates many of the advising problems that students can create. This can help remove impediments to their progress through frequent major changing, often caused by students' difficulty in making long term decisions[11]. The sustained contact fosters long term and self-driven exploration by students. When longitudinal advising is not followed, students can attempt to "game the system" by shopping around for the advice they want. Students often move from advisor to advisor until they find one who will give them the answer they want, particularly in a department that has flexibility to treat special cases of students. This causes problems when students combine advice from several different sources about curricular issues, for instance, and try to create a plan of action that is inherently against the intentions of the faculty. An example may be replacing a core course with one from another department while also changing out another course that then leaves the student deficient in some of the content normally required to be mastered.

Another problem that longitudinal advising avoids involves hearsay or partial information. It is not unusual for students to partially remember some advising details from previous encounters with faculty and then misuse that partial information. Oftentimes, too, students turn to their peers for information and get poor advice on important decisions regarding their academic progress. Longitudinal advising helps ensure that the message is consistent because the messenger is the same each time the student gets help.

The ultimate goal of longitudinal advising in our department is to create engineering students who can self-direct their own career trajectories after their exposure to skills and tools that allow them to explore possibilities. The term "self-determination" is typically encountered in the context of countries and their right to determine internally, without outside influence, how to act. In this case, it means fostering self confidence[12] of students and exposing them to possibility. Discussions lead to an ability to self-direct that is the foundation of all other lifelong learning activities. The awareness students have of their own gaps in abilities and the possibilities they can achieve will guide them in their selection of new skill areas to build on throughout their lives.

It is good to point out here that advising is a pro-active way of building student's confidence by encouraging them to choose their own path and exploring their options. The role of advisor is to help students go not where the advisor has gone, and not where students' parents want them to go,
or not even where students think they should go. It is to help them break through any of these preconceived barriers to find what types of work they are passionate about.

Longitudinal advising involves several access points between students and the advisor that span a considerable length of time. Pre-college recruiting can be used to begin the dialogue, while freshmen events and formal advising appointments can build from there. As students transition to upper division courses, they can explore their courses and external activities with their advisor. Many schools will have some gatekeeper events where students must meet certain standards prior to advancement and will need to meet with an advisor formally at that point. These gatekeepers may have many names but typically come at the undergraduate education mid-point as students transition from lower division to upper division classes or at the end of their academic career for a senior degree check. There are also many other opportunities as students move towards graduation. Interactions between advisors and students, focusing on how to motivate students to explore their own trajectories will be discussed next.

Pre-college recruiting can be both formal and informal, ranging from meeting with students one-on-one to being large scale events with groups of students. Many high school students who have just completed their sophomore or junior years will travel with their families during the summer to explore universities, colleges, majors, and living conditions as they prepare to make their decision on where they will pursue their first degree. Interactions with these individuals are typically on a "drop-in" basis where the visiting families are directed to see an available advisor. More formal summer and academic year activities occur as well. These may include specific summer research institutes for pre-freshmen, outreach programs to local high schools, or mentoring programs with youth groups. Orientation events are another time when students formally meet with advisors to begin planning their academic program. Finally, recruiting dinners for special populations like underrepresented minorities or National Merit Scholars give other access points for advising.

Throughout the pre-college interactions, there are some strong foci for motivating students. One can question students about what they know about their potential major, addressing misconceptions and providing resources for them to explore the majors and opportunities. This is also a good point to begin assembling the background information about students that is critical to their success and their families that will enable the advisor to work within that framework to select possible activities. Parents have strong influences on students' decisions and knowing a student has a family where everyone has a Ph.D. in a discipline related to the student's choice is very different from knowing a student who is the first in their family to leave their small town to attempt a bachelor's degree. Rapport with students can begin to be built as advisors bridge their own experiences to what the students will soon be experiencing. Questioning the student about why they are choosing their major also allows the advisor to select appropriate exploration routes. If a student says they are choosing a discipline like engineering because they love math and its applications, then the advising can direct students to find independent research projects or summer programs where they will be exposed to these types of learning. Finally, a complete student background can be done by filling in information about the students academic background on grades, extracurricular activities, courses taken, and work experiences.
Freshman student advising tends to become more formal than pre-college interactions. There may be opportunities for access during a required freshman colloquium seminar series, through required courses, or through academic advising requirements[15, 16] for specific disciplines. Emails to students directing them to opportunities or to course requirements for prerequisites can help students get on track early for progress through their major courses[17]. There may be many self-sought interactions initiated by students, particularly those who are the most motivated. Course registration for an upcoming semester typically encourages students to seek out advice at that time. Some students will also find themselves on academic probation at the end of a semester and will need to formally meet with an advisor to come up with a plan to return to a successful trajectory. Motivational tools in cases like these are to discuss other students who have found themselves in academic distress who then went on to become successful in their endeavors. Exploratory activities may include finding the right expertise on campus to help students move past problems include seeing a psychological counselor, meeting with legal staff, or seeing evaluators for assessment of learning disabilities that may have emerged over time.

Advising activities designed to foster self-reflection and investigation of career pathways can be built directly into required courses. This is particularly useful when it is done consistently and is evaluated formally as part of the student's academic performance. Assignments that have been used to do this successfully include a one page essay where students describe why they are interested in their major and what aspects of possible careers interest them after a short lecture on the possibilities. Another activity involves a lecture on resumes, their content, and how to structure them to be concise and attractive, followed by an assignment requiring students to submit a resume for critique and scoring. This activity has been done at the freshman level to motivate students to begin filling in gaps in the core areas of work experience, leadership, and scholarship. Sophomores and juniors can also benefit from this activity as they move towards graduation when it will then become too late for any new development. At the senior level, this activity can be done a final time to ensure students have presented their skills the best way possible as they begin to apply formally for permanent positions. Another senior activity that is useful in times of economic downturn is to require each student to weekly submit a list of contact information and copies of cover letters they have prepared and sent out that week as a formally evaluated assignment.

In addition to career related activities, academic advising ones can also be built into core courses. One assignment used at the sophomore level involves explaining the criteria students must meet for advanced standing and progression to the junior core courses, then requiring students to report their completed courses and grades so they can self-assess their readiness for continuation. More informal interactions can also be used for discussing opportunities when faculty are also the academic advisor. The few minutes before and after class as students transition into and out of the classroom provides time for individual advising on issues that students face in their immediate future. Specific needs can be addressed on the spot or more formal dedicated time can be scheduled at that point if the issues are more complex. Interactions like these are one strong advantage of having faculty members also advise students.

Classroom contact with advisors is useful for identifying patterns in student behavior that may impede their success. Examples include addressing students who always put themselves down, students who lack confidence, or students who are shy and may need to be introduced to their
peers to begin interacting. Students who rely too much on team members for projects can also be identified and approached about how their actions may harm them over the long term. Students who have serious character flaws can also be addressed to help them find methods of mediating their flaw. Racism, sexism, and the inability to communicate have been successfully addressed informally and off-line out of the classroom after observing student interactions in the classroom.

Outside of the classroom, contact for motivating students can continue to occur as the students move towards graduation. Emails to course listserves or student organizations can direct students to applications for scholarships, opportunities for developing leadership skills, internships, and summer research programs. Connecting company recruiters with students who fit the desired skill sets can also foster development of student knowledge of their more immediate career options. Encouraging students to diversify their experiences and become involved is another strategy in helping them seek out new challenges that strengthen their portfolio.

A final academic requirement of a formal senior degree check is another opportunity to motivate students to examine their career trajectory. Typically, this evaluation occurs during the semester prior to students registering for their last semester's courses. Longitudinal advising should have prepared students to meet all graduation criteria at this point. However, students can still change their career path slightly through taking on an independent study project or by selecting electives appropriate for the careers they are interested in.

Graduation may not end all interactions between students and their past academic advisors. Students may continue to seek help in developing their career paths over extended periods of time. Students may request letters of recommendation for graduate school applications. Students may need help in resolving conflicts where students may want an outside view of their situation in order to sound out good routes for advancement. Students may want feedback on performance evaluations and how to handle criticism in a proactive way so they can select development opportunities. Encouraging continuing growth is possible with more longitudinal contact.

While past students may often want help, they are also a resource for faculty and their current students. Alumni can be contacted for help in placing students who are looking for internships or permanent employment, especially in cases where the past and current students share some common traits or connection. Past graduates can also be invited back into the classroom to hold discussions about their career paths as a motivational interaction. Connections over time can lead to donations of time, expertise, or money to the department through individual philanthropy.

**Motivating Engineering Students and Retaining Them**

Motivating students appropriately is possible through knowledge of their academic and family backgrounds combined with a long term understanding of the career possibilities students have already explored through the choices they have made. Sometimes, students need more focused help when they are transitioning through a difficult phase in their lives. Students may find themselves in a new family situation through birth, death, divorce, or military service. Students may find themselves working to support themselves while pursuing their degree. Overcoming illnesses or accidents can also lead to academic struggles. Rising to challenges when failure
seems imminent can be fostered by sharing stories of students who have been successful after a circumstance similar to the one the struggling student is facing.

Engineering faces some special challenges in motivating students to stay enrolled. The coursework is often regarded as being the most rigorous and difficult on campuses. The large body of background knowledge needed to begin serious study of the core discipline eliminates many students from programs. However, the heavy course load and academic requirements of being a full time engineering student can frustrate even the best students when they see their friends in other majors seemingly making high grades without a similar investment of effort or time.

Engineering offers some unique opportunities for motivation as well. The financial rewards of remaining in engineering over other disciplines, especially in difficult economic times, and the larger number of employment opportunities are a direct incentive for students. The constant and steady demand for qualified applicants from engineering is stable in both good and bad economic times. Students can be motivated by the intellectual challenge that not everyone can successfully complete the coursework while they have the satisfaction of progress. And, as social problems mount due to resource constraints, the ability to help others through their profession is another strong motivator.

There are certain core skills that students must have in a discipline in order to become successful. Fostering those skills can be done through longitudinal advising. It is assumed that graduates will be technically competent in their selected fields. However, students must have strong written and oral communication skills. These skills can be strengthened in students by suggesting they participate in writing workshops, become student ambassadors or tour guides, or through tutoring other students. Teamwork is another "soft" skill expected in students. Encouraging students to join clubs and move into officer positions over time allows them to build these skills in addition to any team based projects that may be required of students in the classroom. Through extracurricular activities students will also gain a better appreciation of how to learn independently, how to be flexible, and how to be persistent.

There are some gatekeeper assessments used for controlling student access to some opportunities after graduation. Students must have a resume for graduate school applications and permanent employment. A resume well populated with leadership activities in addition to relevant work experience helps candidates secure better offers. A strong GPA may also be needed for some possibilities like admittance to a highly ranked graduate program or receiving an offer from some companies that may have a 3.5 GPA requirement. Students who can demonstrate a good life balance through outside activities have advantages over other students. Longitudinal advising allows students to start with smaller activities and continually leverage their experiences into higher level interactions. One example is for students to become a general member of a club one year and then transition into a position with the officers of that club the following year.

For some disciplines, other gatekeepers include professional certifications students must fulfill. This may include passing the Fundamentals of Engineering exam or completing hazardous waste management training through OSHA, among others. Any activities students can do ahead of time to prepare for their successful completion of these other demands will make them more
attractive for hiring. Longitudinal advising allows information about all of these topics and their importance to be shared with students when they still have time to enhance their development.

**How to Create Opportunities for Longitudinal Advising**

Much time has been spent discussing the benefits of and how to implement longitudinal advising in the framework of undergraduate experiences. The discussion will now turn to how longitudinal advising can be encouraged at the departmental or institutional level. One recommendation is to assign pre-majors or freshman directly to one advisor who they will be engaged with as soon as they have contact with their major, possibly even prior to students seeking out help. This advisor would then remain their advisor until they complete or leave the program. Another recommendation is to only have advising by those faculty or staff who are passionate about this activity. A mediocre to poor advisor who followed a student longitudinally could do more damage to student motivation than a short interaction with a good advisor can compensate for.

Department heads and curricular chairs can foster connections between faculty and advisors if they are not the same people by hosting short meetings oriented around sharing information. Advising deadlines and methods of fostering self determination within students as discussed previously in this work can be shared with faculty to be incorporated into courses. Faculty members, in turn, can provide a list of concerns students have voiced about issues relevant to them, or can help in identifying those students who may face special challenge so advisors can follow up. Professional staff who have contact with students could also be included in this meeting. One meeting perhaps once a semester would allow for contact and sharing of this information.

At the college and university levels, adequate training and exposure to student resources should be provided to all advisors[18]. A single pamphlet that organizes all support offices like disability resources, tutoring, counseling, etc., could be provided at the beginning of each year to remind faculty of their existence in a concise place. Release time from other service duties will also enable faculty and staff to provide the best in advising services longitudinally. Recognition of accomplishments in this service arena will reward faculty for the patience and determination to help students in reaching their highest levels of achievement.

**Conclusions**

Longitudinal advising is a way of consistently motivating students to reach their highest potential. One plants the seeds of ideas that may grow fruit over time through exposure to new skill areas or information. Students can learn how to be flexible through evolving interactions with their advisor when they adapt to students' changing needs. Impediments to personal growth can also be removed when they are small or manageable. The sustained interactions over long periods of time allow advisors to know the students well and help them transition to lifelong learning professionals who are successful.
References


Biographical Sketch

Paul Blowers received his PhD from UIUC in 1999 and has been a professor in chemical and environmental engineering at the University of Arizona since that time. He has been recognized as a top educator at the departmental and regional levels and in the past year was recognized as the best faculty academic advisor at his institution. He then went on to be selected as one of the top four faculty advisors in the U.S. by the National Association of Academic Advisors.
Use of Concept Maps to Build Student Understanding and Connections Among Course Topics

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Abstract

Students often have a difficult time becoming strong engineering students because they are used to some of the prerequisite courses in science and mathematics being somewhat formulaic and "plug-and-chug" in their approaches. When students have been challenged by prior courses that are not formulaic, they often rate them as being harder or complicated. The transition of becoming more broad-thinking in problem approaches is a difficult one, even for very hard working and bright students. Concept maps enable instructors and students to more concretely describe connections among different course topics and to place new knowledge into a comprehensive problem solving framework.

Examples of concepts maps from a series of chemical engineering courses are used to discuss how the idea of concept maps can be used in different ways. Concept maps built over the semester for a sophomore material and energy balances course are used to highlight how layering of new concepts and an inherent increase in complexity leads to a comprehensive overview of material. Use of the concept map in lecture example problems demonstrates how one can utilize the given problem statement to see how solutions to conceptually challenging problems are built. A concept map from an equilibrium thermodynamics course at the junior level is used to show how disparate yet interrelated ideas can be bridged together through a hierarchical definitional approach. Finally, a concept map illustrating sustainability in the context of technical, social, economic, and environmental issues for a senior design series is examined for pedagogical relationships on why certain topics were selected for the courses.

Student feedback has consistently shown that the idea of concept maps enables students to solve more complex problems with greater confidence. Students have also indicated that they have developed concept maps for subsequent courses on their own, even though it was not required and instructors did not encourage these efforts. Students seem to benefit from these activities.

Introduction

Faculty in engineering often suspect that prerequisite courses in science and mathematics are focused on formulaic approaches to solving problems. This is sometimes called the "plug and chug" method where students may not understand the fundamental concepts but will superficially link mismatched concepts together, leading to poor performance in the prerequisites and a weak foundation for building the core engineering topics. Sket and Glazar observed high school chemistry students who did not organize their knowledge, knowing the individual reactions, but not how to link a series of reactions together. Students in the prerequisite science courses, then, may be attempting to learn more superficially than what will be required of them later on. This view of teaching and learning fits well with an investigation of how some faculty
see teaching as transmitting information and students learning as receiving this information\textsuperscript{2}, without much focus on how the information really functions. The work by Hendersen, et al., used a focal problem from physics to investigate faculty perceptions of teaching and learning problem solving where the problem would require an average student to use exploratory decision making as opposed to an algorithmic or "plug and chug" approach. A significant number of faculty viewed their role as a knowledge transmitter and not a problem solving enabler.

Much of the material in prerequisite courses prior to the beginning of core engineering courses is oriented towards factual recall. It is on these foundations that the engineering problem solving skills will be built. Ausubel's theory of assimilation\textsuperscript{3} points out that linking to prior knowledge is a key to building long lasting and useful skills. In essence, knowledge must be organized in order to be accessible from long-term memory\textsuperscript{4}. Students who possess isolated information about concepts on a factual basis will remain novices and be unable to solve complex problems.

Students often have difficulty transitioning from fact recall courses to more integrated and informationally cross-connected courses in engineering. This may be because students have yet to learn how to create a scaffold for holding new information in a coherent whole where topics are related to each other. Concept maps may be one way of enabling students to succeed in overcoming this difficult transition to problem solving and critical thinking.

**Concept maps and their history**
A recent meta-analysis of concept and knowledge maps points out that diagrams like these originated as far back as the 13th century\textsuperscript{5}. However, their use has seemed to explode recently with a much larger number of publications appearing in the literature. Even just since 1997, there have been 500 peer-reviewed articles that have investigated their use, according to a brief survey of Journal Citation Index.

Novak\textsuperscript{6} proposed the concept map as a way of created a knowledge network that contains points and verticies as concepts and links between them as the relationships among concepts. Kinchin and Cabot point out that there have now been 25 years of extended research and development of using concept maps to help students learn how to learn\textsuperscript{7}. Essentially, concept maps are two-dimensional representations of a set of concepts and their relationships\textsuperscript{8}. Being graphical in nature, they show the conceptual, relational, and hierarchical nature\textsuperscript{9} of topics in a course or series of courses.

**How instructors use concept maps**
Concept maps have a rich history of application in the medical education literature\textsuperscript{8-10}. For instance, concept maps have been used to evaluate student learning of CD-ROM based educational materials in MRI imagining\textsuperscript{10}. Hay, et al., showed that concept maps could be used, even in small classes of only six medical students, to investigate how deeply and richly students perceived new topics after a short-term assignment requiring use and assimilation of a 6-8 hour long electronic teaching tool that covered both case studies and more rote learning through a tutorial. Students drew a map of their pre-knowledge of MRI technologies and then drew a second one after exposure to the material. Students were evaluated on the structural changes in the hierarchy of organizing concepts, their use of expert terms, and then through a blind-evaluation of the pre- and post-mapping exercises. Of the 78 concepts detailed by instructors,
only 28 showed up on any of the student maps, and at that, only half of the module sections were represented. It was noted that preknowledge of the material or prior experiences were a very strong determinant of the final concept map structure. The authors ended with a suggestion that the concept maps may have wide-ranging utility that may help some students more than others, particularly noting that concepts maps were a visual representation of linkages between material.

Diwakar, et al., used concept maps extensively to teach physiology to veterinary students. Their work was motivated by the fact that concept maps provide a visual road map showing how students may connect meanings of concepts together. The authors expended effort developing assessment tools for evaluating student-constructed concept maps. A preliminary study of their method was done with freshman students who were graded on maps they had drawn. Forty-eight percent of the students reported liking the concept maps, but 28% did not like them. The authors went on to use concept maps extensively as a student assessment tool in a first-year veterinary medical school course on physiology. The course consisted of two exams, seven quizzes, and 11 concept-mapping assignment in addition to five laboratory reports. The concept mapping exercises constituted 17.5% of the total grade in the course. Students were surveyed about their likes and dislikes of the concept maps and only 21% reported liking concept maps, but 81% felt that concept maps helped them understand material and 68% thought it helped them organize information. So, while students don't like them, they self assess themselves to benefit from them, indicating there may be some resistance to using concept maps as an assessment tool. Students reported spending about 3 hours in developing a satisfactory concept map and that it took them an average of 3.3 attempts to create one they liked.

Kaya discusses using concept maps to evaluate the changes in the conceptual understanding of 47 prospective science teachers in a general chemistry laboratory class. Their goal was to develop assessment tools that would prove the acquisition of higher-order thinking processes instead of just factual recall and basic skills. The structure of the course was a 15 week long semester with 3 hour labs. Students spent one semester prior to the one with this course learning how to develop and use concept maps and then they were evaluated on their concept maps in the course. Students were asked to individually prepare concept maps prior to the laboratory exercises and then they performed peer evaluations of each other's maps. After completing an experiment, students again did their own maps and then peer evaluated each other. Expert evaluation of the pre- and post-lab concept maps allowed for an examination of how deeply students were learning the material, and the author found that for almost all topics, students developed concept maps that were more interconnected and complete after the experiments. Quantification was difficult to score and the process of evaluation was very cumbersome in that work.

Moni, et al., worked with second year dentistry students to explicitly teach concept maps to facilitate meaningful learning for a four week long segment of the course on cardiovascular, respiratory, and renal systems. Concept mapping exercises and scores contributed to six percent of the students' final grades. During the four weeks, students participated in a 50 minute long introductory workshop on concept maps on other topics. Students were then given a case study where they worked in a team for 1 week to make a concept map detailing the interrelationships between different concepts and the case study. The 1 week time period included a 2 hour workshop where students discussed their work with the faculty members. Two faculty members
then evaluated the concept maps with a complex quantitative scoring system, discussed differences in their scoring, and then led mediated discussions with the students to arrived at the final grades. Finally, students were given a survey about their experiences and 42% of the students felt that concept maps help put everything together linking multiple concepts, but 40% thought the exercise was too time consuming but worth the effort. In a follow up work, the authors used their newly designed assessment rubric and investigated student opinions of the tool more. They found the concept mapping activities were not favored by students but that their like/dislike of the tool correlated with their grade.

Schau and Mattern discuss additional uses for concept maps other than in assessment. They point out that instructors can use them in instructional planning, which will be discussed later on in this work, and as learning tools. Concept maps are effective learning tools both when given to students and when created by students. As discussed before, creating concept maps forces students to attempt to organize information. However, having concept maps provided allows the students to see a hierarchy or overall structure to which they can anchor new concepts within the framework of their own understanding. Schau and Mattern also discussed some quick and efficient methods of using concept maps that have not been discussed in the other works, which is to use them as a template where varying degrees of node identifiers or links have had their labels removed and students must fill in the missing information. This can be done either without providing them with the missing information or by also giving them the list of information to be added. These instruments are extremely easy to evaluate compared to the previously described assessment tools.

Kinichin and Hay showed one could use preliminary concept maps to aid postgraduate trainee teachers learn aspects of biology. They used the preliminary maps to build teams of students who then worked collaboratively to flesh out more complete maps that detailed the topics. The students received 2 hours of concept map training followed by developing individual maps and then creating a group one. The authors described three types of concept maps to elucidate how to build the teams, spokes which were very straightforward, chains, which only had linear connections among ideas, and nets, which had more node connections among different levels. These net diagrams can be used to employ technical terminology to enhance meaning, in their view, and it is nets that will be used later in this work. They pointed out that concept mapping tools for learning are often underutilized, but do not discuss, much as others have, how one can actually use concept maps to enhance deeper problem solving skills instead of just in building a fact/knowledge diagram.

Pre- and post- exposure to material concept maps were used by 32 freshman students in evaluating self-awareness of limitations of missing knowledge of computer hardware. Students drew one concept map on their own regarding the material using a somewhat constrained computer-based tool before comparing their maps to those of their peers. Students then redrew their own maps. Pre- and post-maps were evaluated by three experts who were trained with the same computer-tool and with the same terminology. Unfortunately, only 25% of the students thought the mapping procedure helped them find conceptual faults.

Kinichin and Cabot point out that there has been a shift towards PowerPoint based lecture materials in many disciplines. Unfortunately, much of the information presented in the
PowerPoint format is organized in bullets that are sequential in nature, often burying connections among topics in the details of the sequences. However, concept mapping promotes integrated knowledge structures using multiple perspectives that are focused on meaningful learning. In their short work, the authors used PowerPoint-based concept maps to supplement learning for 37 third year undergraduate dental students in a section of a course dealing with the problem solving aspects of developing a partial denture design. Students were given two separate PowerPoint slides, one that was a traditional bulleted format of the information and another that was a concept map showing relationships between content. Ninety-two percent of students reported that the slides in the bullet-point format helped in memorization while only 43% said this of the concept map format. However, 95% of students felt the concept map helped show connections between individual concepts. Unfortunately, there was no evaluation of whether student perceptions carried forward to improved performance.

Another paper pointed out that instructors could use concept maps to help students better tailor their instructional approaches in e-learning environments. The paper then went on to develop fuzzy logic analyses to automatically generate concept maps for courses using student performance on exams as a guide. The generalizability of this approach may not be feasible for open-ended engineering format questions and material.

Creating access to prior knowledge and activating students to be receptive to new linkages was explored by Gurlitt and Renkl with 43 high school and 45 university students using physics as the subject matter. The premise is that students primed to access prior knowledge would be more involved in developing deeper linkages among concepts on a particular topic. The experiment was very short in duration, approximately 1 hour and 15 minutes, where students were exposed to the idea of concept mapping, given a partially constructed expert map, and asked to fill in additional information. After that, students were given access to web-based textual materials that explored different topics. Students then took a post-test of the material and contained both open ended and multiple choice questions. While there were many inconclusive results, the authors found that there was enhanced learning after use of the concept map to activate areas of prior knowledge and prerequisite material.

Development of concept maps was linked with learning styles in a study of 120 nursing students. Again, the main theme in nursing like in engineering education, is to develop critical thinking skills in students which includes interpretation, analysis, evaluation, and inference with the ability to provide the rationale for one's judgment. Concept mapping was proposed to be a method of evaluating meaningful learning on the basis of Ausubel's assimilation theory. In the study, students were invited to participate, which may have led to some self selection effects. Data collection was brief, with two 10 minute assignments during the semester, one to complete a learning styles survey instrument and one to complete a concept map. Concept maps were then evaluated by faculty members using an internally consistent peer comparison ranking process, which may have had some subjectivity. The learning styles groupings did not include a visual-verbal category so it is interesting to consider whether the inclusion of this type of axis from Felder's work would have led to stronger correlations. In the nursing work, abstract learners were twice as likely to have preferred using concept maps over more traditional case study materials. The authors ended with the idea that concept maps may be more effectively used as teaching tools than as grading or evaluation assignments.
Only one paper in the literature surveyed by the author discussed using concept maps as a teaching tool as suggested in the previous paragraph, and that was the work of Sket and Glazar. The authors lay out a hierarchical detailing of organic chemistry synthesis reactions using oxidation/reduction mechanisms as one axis and individual reactions along the other axis. The authors then show one example of how one could use their concept map to answer a fill in a homework exercise, leading the reader through how to use the concept map. They give a few other simple examples that would rudimentarily benefit from the concept map. They end with the thought that elaborated concept maps enable students to integrate concepts successfully.

A meta-analysis published in 2006 examined 55 studies involving 5818 participants ranging from elementary school age through post secondary education participants. The study broke the studies up into several major categories in their analyses, finding that concept maps aided in instructional goals and student learning in almost all situations, at all age levels, in all contexts. In particular, student construction of concept maps appeared to be very useful, although even just studying a preconstructed concept map led to some educational achievement enhancement. Working on concept map development also appeared to improve learning outcomes in collaborative learning and peer interaction exercises. The authors mention early in their work that concept maps may aid learners because verbal knowledge and mental images reside in separate but interlinked memory units. This is interested in light of Rich Felder's work on identifying the visual/verbal axis in his learning styles assessment materials.

Anecdotal information from the author's surveys of students over a 10 year period have revealed that about 90% of honors freshman at the home institution are visual learners, indicating that text only materials may not be the best way of fostering student learning, even among very high achieving students. A visual representation of connections between topics on a concept map is also easier in identifying links compared to scanning and re-reading text only materials. The authors of the meta study go on to suggest that maps my be useful because they reduce the difficulties in placing new material into the context of pre-existing knowledge. This may be due to the visualization engendered by the representation of the material.

The meta-analysis points out there is a strong need for assessing learning outcomes beyond conventional free recall and research-constructed achievement tests, which are primarily multiple choice or short answer assessment tools. The authors suggest that more work should be done to examine how students learn with concept maps and their effects on higher learning goals, such as problem-solving transfer, application, and analysis.

How students use concept maps
From a learning perspective, concept maps may enhance learning when used to summarize information. Maps may be good for acquiring main ideas but may do poorer at helping students acquire detailed or nuance-laden knowledge and this may have some interesting impacts on how concept maps can be used effectively. Additionally, maps may be easier to comprehend for learners who are studying in a non-native language, possibly enabling them to draw larger inferences quickly even with language comprehension impediments. This may have implications for engineering students where large numbers of undergraduates now come from overseas.
Hilbert and Renkl did one of the more involved studies of investigating concept mapping strategies as a method for students to integrate textual information about a new topic\textsuperscript{22}. Thirty eight university students were asked to read a series of articles about stem cells taken from newspapers. They were then asked to verbalize some statements about them, asked to then make concept maps of the information from the articles using a software tool for 30 minutes, and then redraw the maps after rereading the articles. The students were then given a multiple choice test and an open ended question about stem cells. In addition, students took intelligence tests that were designed to assess their verbal skills and their spatial/visual skills. The authors correlated information to answer a series of hypotheses. This is one of the few prior studies that have looked at visual abilities as related to the use of concept maps. Sixty-three percent of the students in the experiment had not been exposed to concept maps prior to this exercise. Students, in general, had learning increases on the multiple choice questions after reading the articles and doing the maps regardless of their spatial or verbal skills. However, on the open ended integration question, visual learners scored higher.

Finally, it is interesting that in most concept map applications, students have been asked to either construct concept maps or have been asked to study content on them. To this point, there has been no work on actually using concept maps to foster development of problem solving skills in the context of real problems.

**Approach in this Work**

The author of this work has long been involved with exploration of educational techniques of fostering student learning in both breadth and depth of their abilities to reach mastery of material. The topics integrated so far have included use of web-based interactive problem solving tools online\textsuperscript{23}, enabling freshmen students to transition effectively to college\textsuperscript{24}, creating syllabi that foster communication among faculty and students\textsuperscript{25}, information literacy\textsuperscript{26,27}, integrating sustainability into senior design\textsuperscript{28}, and predicting sustainability metrics through quantitative measurements\textsuperscript{29}. In addition, there have been other papers on the arguments for a straight grading scale in engineering\textsuperscript{30}, the balance between teaching and research at different institutions through a quantitative investigation of pedagogical publishing\textsuperscript{31}, and forming balanced teams through students' self assessments of their own abilities\textsuperscript{32}. This summary is included here because some of the themes that have emerged over time bear on this work and show that creation of concept maps and their use is logical. The interfaces among the different educational topics will be discussed where appropriate. Much of the work on integrating new learning and teaching approaches was done to foster learning for students with different learning styles.

Felder and coauthors, as previously described, have long explored different learning styles for students and teaching styles of faculty and how those interact for student success\textsuperscript{18-21}. In relation to this work, students who learn best from global approaches may find the use of concept maps useful in synthesizing a coherent framework on how new material is connected together. Sequential learners, the other end of the global-sequential continuum, may find that they can piece together longer chains of problem solving events when they can see more complex interconnections than sequential trial and error may allow them to experience. Visual learners may also find the map format more useful than verbal descriptions of connections. In the context
of these learning styles, there have been three major uses of concept maps in courses taught by
the author that will be highlighted using examples from the most recent offerings of each course.

Sophomore Material and Energy Balances
In the sophomore material and energy balances course, there were a total of 94 students who
finished the course out of the 103 who began the course at the beginning of the Fall 2008
semester. This course is the first core course in chemical engineering and is one of the two
options engineering management students must take in order to meet their energy-based
curriculum content requirements. Students in engineering management may take this course
during their sophomore, junior, or senior years, while chemical engineers will be sophomores.

A variety of instructional support tools were used in this course that had an impact on the use and
evaluation of concept maps in student learning. These tools were primarily computer-based and
included the use of Desire to Learn (D2L), a comprehensive tool for organizing course
information and tracking student use of online content, the use of OneNote, a powerful software
program that utilizes PCTablet technology to allow one to write on a virtual notebook page while
archiving verbal statements made during class, and Microsoft Excel, Word, and Powerpoint files
posted on D2L.

The primary use of concept maps in this introductory course was to facilitate student integration
of new concepts into a coherent framework that allows them to solve complex problems.
Because this class is oriented towards solving unique and new problems as opposed to being
"plug-and-chug", this may be the first time that students are forced to integrate complex material
at a deep level. Prior to each exam after the second exam, an integrated picture of
interrelationships was constructed that showed how the complexity of the material grew while
branches leading among disparate areas allowed one to handle more phenomena. Additionally,
late in the semester, concept maps were used in the context of individual problems to help
students organize the given information and begin formulating solutions. Samples are shown
later in this paper.

Junior Equilibrium Thermodynamics
The core second thermodynamics course in chemical engineering at the University of Arizona
contained 38 students who completed the course out of 39 who began the course in Spring of 2008.
This course is in the fourth semester of core courses so students should be strong problem
solvers at this point in their academic careers.

The concept map shown later was originally constructed by the author the first time they were
the instructor for this course. In many institutions, the equilibrium thermodynamics course
becomes a repository of topics that may not fit together into a coherent whole and the author
struggled to synthesize the connections between the seemingly disparate topics. With the core
relationships worked out, it then became possible to connect all of the material rationally while
also building an end of the semester project that required students to use the interconnections
between course content.
Senior Design
The senior level chemical engineering class in the Fall semester of 2008 had 36 registered students who began and completed the course. Senior design at the home institution has undergone many changes over the last several years\textsuperscript{33}, the largest change being the integration and distribution of sustainability and related topics into the senior design series. The third year after this integration was done, a concept map was constructed to help students see how sustainability of technologies and decisions could be affected by social, economic, technical and environmental issues. This concept map is shown later on in the results and discussion.

Results and Discussion

Concept Map Uses and Details: Figure 1 on the next page shows a sample of the concept map first included in the sophomore course lecture, drawn in real time with students generating the concepts that showed up on course objectives while the instructor linked the concepts together prior to an exam. The figure is a screen shot from the OneNote program which functions as a computer-based notebook where one can draw freehand or type in information. This concept map outlines the first five chapters of Felder and Rousseau's Elementary Principles of Chemical Processes\textsuperscript{34} text typically used with beginning chemical engineering students.
Figure 1 - A freehand example of a concept map drawn during class using the OneNote Program. Material on this concept covers almost all of the first five chapters of the text chosen for the sophomore material and energy balances course.

The concept map includes information about basic variable transformations like using specific gravity (S.G.) on the top of the diagram to convert to density ($\rho$) using a reference density ($\rho_{ref}$). Density can be used to convert from mass balances, represented in a circle as one of the fundamental cornerstones of the course, with volumetric amount of flowrate, represented as $V$-dot. In the center of the diagram, mass balances are connected to mole balances through the molecular weight (MW) link that interconverts between those two ideas.

In Figure 1, there are two major branches off mole balances. The one on the left labeled reactions (rxns) leads down to a laundry list of concepts and definitions that students should be familiar with from chapter 4 in order to be successful in problem solving. Another major branch leads down to the right from mole balances through the ideal gas law ($PV = nRT$). Some feeder information from the bottom of the diagram includes manometers, represented with the letter $h$ for height difference between manometer fluid levels. This information is transformed through a gravimetric analysis ($\rho gh$) to pressure, which can be used to relate gauge to absolute pressure through atmospheric pressure. It is absolute pressure that must be used in the ideal gas law. The
ideal gas law can be used to convert moles to volumes for gases, often requiring some temperature conversions shown on the right side of the figure.

The final concept on the map is velocity represented with u-dot in the upper right of Figure 1. The velocity can be found from knowing the volumetric flowrates of either liquids or gases and the cross sectional area for flow. At this point in the course, students now had a concept map that linked the flow of information for different problems that can be covered using topics from chapters 1-5. In the upper left of the figure, there are some other concepts that overlay all of the problems and indicate core knowledge that must be assimilated in the context of the rest of the map. One needs to know how to manipulate unit conversions, how to use definitions properly, and how to understand what different pieces of equipment can do and how to model them.

Figure 2 shows how one can solve a simple problem using a concept map approach to indicate how information moves and in what order calculations can be done.

In the above problem, one is given the fact that a gas is flowing through a tube that has a decreasing diameter. The inlet and outlet conditions are given but students need to find the final velocity. Students need to figure out that they transform the given diameter of the pipe into a cross sectional area for flow, which is multiplied by velocity in the upper left of the diagram to get volumetric flowrate. In order to use the ideal gas law to get the number of moles flowing through the tube, one needs to convert the temperature to degrees Kelvin from Celsius and the gauge pressure to absolute pressure. One then uses the concept that the number of moles flowing into the tube must be equal to the number of moles flowing out of the tube. The entire right side of the diagram is then a pictorial representation of how the same information and calculations
flow backward in a symmetrical way to yield the outgoing velocity. This concept map shows how a single problem can focus discussion on connection.

Figure 3 shows another example from 10-26-08 where a concept map was used in the sophomore course to show how information flowed through a problem towards an answer. The problem in this case is a classical example in chemical engineering where the inlet volumetric flowrate of a gas to an air conditioner is specified in addition to the temperature and pressure. The question then requires students to solve for the amount of water that would be condensed out from this air as it is cooled. The concept map shows that one uses the ideal gas law to find the molar flow ($F_1$) of the gas. One then uses the temperature to solve for the vapor pressure of water $P_{w^*}$ on the bottom of the figure. One assumes the total pressure ($P_{tot}$) stays constant and that only pure water is being condensed $x_{2,w} = 1.0$. This allows one to find the molar composition ($y_{3,w}$) of water in the exiting air using Raoult's law. At this point, one must solve two equations with two unknowns to arrive at the answer. This is typically a complex enough problem that many students will be lost by the end of the solution. In this instance, the problem was sketched and the equations were sequentially solved. After completion of the example, this concept map was drawn as a summary of the steps to connect the answer to the information stated in the problem.

Figure 3 - A concept map for material from an advanced chapter that integrates material about equilibrium and Raoult's Law with a mass balance and ideal gas law using a single problem as an example.

Figure 4 shows a complete concept map for the entire course's material up through chapter 8 of Felder and Rousseau, which is the final chapter covered. One now sees that much of the information from earlier figures has been redrawn and that there is a new locus of connections on this diagram, which is for energy balances that are used to complement the mass and molar balances.
There are some more details that are included now. The addition of Raoult's Law seen in the previous example and the vapor pressures ($P^*$) coming from Antoine's equation, Cox charts, or vapor $P^*$ tables have been added on the left near the manometer information. Some definitions regarding relative humidity (r.h.) and saturation (satd eq.) have also been added that lead to mole fraction concentration relationships ($x, y$), that then feed into moles and mole balances through the lower left portion of the diagram.

Energy balances appears as the third core concept in addition to mole and mass balances. And now, since there is some symmetry to the diagram to get from moles or mass up to velocities that then feeds into the kinetic energy term of energy balances, you end up with two pathways through volumetric flowrate using area to get to that point, one for liquids and one for gases. Potential energy, heat ($Q$) and shaft work ($W_s$) also appear leading up towards the top of the diagram where internal energy ($\Delta U$) and enthalpy ($\Delta H$) appear. One can then bridge over to specific internal energies and enthalpies ($U$-hat and $H$-hat) to the left through temperature and pressure information. One can also calculate enthalpies and internal energies from integrals of the appropriate heat capacities in the upper right. Phase change information may also be needed through $\Delta H_{vap}$, $\Delta H_{fus}$ and $\Delta U_{vap}$, $\Delta U_{fus}$. It should be noted that even after several years of using concept maps in the course, the instructor still made three attempts to reach this final form that seemed most clear.

Figure 4 - A complete concept map for the first 8 chapters of Felder and Rousseau's book, including energy balances in addition to the previous material from earlier figures.
Figure 5 shows the same concept map as Figure 4, but now used in the context of a real problem solution. In this problem, students were given a feed rate to a boiler in moles/time, a cross sectional area for the feed, inlet temperatures and pressures and the fact that it was liquid water being fed. The outlet was at a higher temperature and lower pressure, causing the formation of a vapor after the valve (the piece of equipment in the process). The final velocity was also specified while the students were asked to find the diameter of the exiting pipe. This is a classical steam table problem in chemical engineering with a liquid entering and vapor leaving.

The first step in using the concept map was to circle all pieces of information from the problem statement and these circles appeared in red, as shown in Figure 5. With that done, students thought the problem solution could lead to 2 equations with 2 unknowns so a note was made of that comment (2eq. 2 unknowns). Overwhelmingly, students thought mole balances would be the route to go based on their earlier experiences with problems already shown in this work that used the ideal gas law for an pipe diameter changing problem.
Students confident in their brainstorming of approaches to the problem that there would be an energy balance through the first law of thermodynamics represented in the central vertical list of ideas, including the fact that Q would be zero for an adiabatic system (circled in red). Two students thought that one could use the fact that steam/water vapor was involved to directly link velocity of the liquid and the cross sectional area through specific volume (V-hat and not listed on the diagram) through the steam tables, which ended up shortcutting the solution steps by about 5 or 6 manipulations. The discussion about steps and process was open to all students and there was much debate about the variables and how one could use them to get to the end point of area (A) and the diameter (not shown) for the gas in the middle part of the diagram. The author can comment that this was the first time a problem this complex was solved through presentation of a concept map in the class in addition to the problem statement where students drove the discussion. There was a lot of interplay among students as they discussed with each other what links led where and why some were not viable. This experiment of applying a concept map in a real time solution of a complex problem seemed to be a success as students brought copies of their maps to other classes and were annotating them and using them as starting points for exploring problem solutions throughout the rest of the semester.

Figure 6 above shows a concept map that is related to Figure 3 in that this is another problem involving Raoult's law around a piece of equipment. This time, students were told they had a
humidifier and the flowrate of air in mass per time was specified in addition to the temperature and relative humidity. They were told the process was adiabatic and that water at a certain temperature as a liquid was added to the gas stream. The end result was a stream that had a specified relative humidity. The students were asked to find the final temperature and the amount of water that needed to be added to reach the desired relative humidity.

Based on previous problems and concept maps, students quickly realized there was an energy balance involving the adiabatic system where Q was zero. This then led them to the idea that enthalpies could be used (not shown on the diagram due to the pace of the discussion). However, the major thread of the solution went from mass in the lower right back through mole balances, through Raoult's law in the lower left, through relative humidity as a definition and then up to pressure where it was assumed to be 1 atm due to the system being open to the atmosphere. Students again argued back and forth about including some links over others before they solved the problem based on the concept map.

Leaving the sophomore class where the concept maps were used as problem solving tools and as prompts for review of material, concept maps can also be used to enable global learners, those who assimilate information in totality instead of sequentially, to get an idea of the structure of material and where new pieces will fit in as they are learned. Figure 7 shows a concept map handed out and then used during a junior equilibrium thermodynamics course.
In many chemical engineering thermodynamics courses, only the material in the upper left of the diagram is covered, particularly how to handle non-ideal vapor liquid equilibrium (VLE). In the course for this map, connections are made to liquid-liquid equilibrium (LLE) and solid-liquid equilibrium (SLE), in addition to solid-vapor equilibrium (SVE). The right hand side of the diagram shows that the very fundamental starting point of the class with definitions of equilibrium at the top of the diagram is the primary link to an entire second branch of reaction equilibria on the right side of the diagram. And within each topical area, there are details and subtopics that allow for greater investigation of different physical phenomena. The concept map in Figure 7 was used as a review tool before each exam in conjunction with the course objectives listed on the syllabus. The map was presented to students and students were asked to circle the parts of the diagram where homework had already been evaluated and returned, indicating to students what material was fair for coverage on the upcoming exams.

Prior to the creation of the concept map shown in the above figure, the instructor had experienced equilibrium thermodynamics as a series of disconnected modules with no common theme as discussed earlier. However, after creation of the visual map, they were able to conceptualize larger and more complex projects that would probe student understanding of the details in each area while sharing with them the power of the theories underlying the concepts.
Figure 8 shows a concept map used in the chemical engineering senior design course. Again, this concept map is furnished on the first day of class and then students are referred back to it as the co-instructors move back and forth among the different topics.

**Figure 8 - A concept map for a chemical engineering senior design course where sustainability themes and topics have been interwoven into a more traditional course.**

Sustainability, the ability to meet current needs without compromising the needs of future generations, has been included into a traditional chemical engineering senior design course in this case. In the typical senior course, it is common to cover process flow diagrams (PFD), pieces of equipment, a simulation tool like ASPEN for chemical processes, rules of thumb for design, economics, and energy and material recycle strategies. A traditional course will also include oral presentations, writing exercises, and some elements of dynamics. Sustainability topics that have been included are life cycle inventory and life cycle assessment as tools of evaluating sustainability (LCI and LCA), global warming potentials (GWP), safety, unintended consequences of technologies and processes, and decommissioning of facilities and rehabilitation of industrial brownfields. Throughout the course, information literacy has been introduced as a way of using popular and peer reviewed media to organize decisions around quantifiably sustainable processes.

This concept map was created in the third year of the course's offering as an integrated one with sustainability. It is interesting because students during the first two years had often commented on their anonymous teaching evaluations that they did not see why the topics were even in the same course. Also, students had pointed out that the sequence of material was random to their eyes. Those comments were valid in that the instructors rearranged the material around travel schedules. However, after the creation and introduction of the concept map, students no longer questioned the ordering or connections among the material. They could see how one could move between the environment and economics through one connection of environmental economic theory and decision making, or one could consider making process modifications through minimum energy need analyses or by creating material recycle loops.

In this paper, we've shown how concept maps have been used in different ways. First, like some of the works in the introduction, concept maps have been used as review and summary tools.
Students were provided with a map or ones were generated in course discussions using objectives listed in the syllabi. Similarly, the concept maps in Figures 4, 7, and 8 show how connections among material can be provided to students as a guide that helps both global and visual learners. On the other hand, this work is the first one that explores the use of concept maps during problem solving as a way of exploring how information can be transformed and aggregated to lead towards the end goal of a problem solution. This use was highlighted in Figures 3, 5, and 6.

Two evaluation tools will be examined in this work to examine student use of concept maps and successful outcomes. One evaluation tool will quantifiably examine whether student access to posted lecture materials was more frequent on days when concept maps were archived. Another assessment will involve student self-reports of their use or usefulness of the concept map approach.

Quantitative Access of Archived Concept Maps:
The first analysis of student use involves combining data from the D2L course management software used in the sophomore course with the content of each lecture's posted content. The D2L tool allows the instructor to monitor who accessed files and on which dates throughout the semester. A review of all OneNote lecture files showed that a concept map was first included on 9-29-08 and included the first five chapters of material. On 10-10-08, another concept map with more layers of connections was presented in the context of solving one problem solution. On 11-26-08, 12-1-08, and 12-3-08, larger concept maps, including almost all content from the course, were used in solving problems.

One would expect that the dates with those lectures would be more heavily accessed than others if students were responding to the introduction and use of concept maps. Figure 9 shows that student access to materials did not track with the dates when concept maps were included in the archived material. Another work shows other trends in student use that more strongly correlated with access to the online materials. These correlations include scheduling proximity to exams and the difficulty of the material. It is possible that future work could post concept map materials separately so better control over measuring what the students were specifically accessing would be possible. As the data stands, there may be multiple elements of a given lecture that led to the downloading of those materials over other lectures.
Anecdotal Information about Student Use and Views of Concept Maps:
In addition to the attempt to quantify student use of concept maps compared to their posting in lecture notes, student anecdotal stories also provide some insight. One student in the sophomore course stated that the concept maps enabled him to see connections he normally would not have and he went on to ask for help in constructing a concept map for the organic chemistry course he was enrolled in. He was then provided with a sample organic chemistry concept map encountered in the literature during the writing of this paper. He commented that the reactions were now falling into patterns for him as opposed to being unlinked.

Another student, prior to the generation of the final sets of concept maps in the sophomore course, filled in and connected the details of new material to the existing structure from lecture. He commented that the exercise enabled him to solve the more complex problems with regularity. In the end, he credited his success in the course to using the concept map on every problem.

A large fraction of the class had representations of the concept maps in their study materials allowed during the exams in the sophomore course, choosing that content over other information they could have chosen for the limited space available. While a formal count of this was not done, approximately half or more of the class selected concept maps as material they used during the exams.

The sophomore classroom environment involves many active learning techniques. These techniques often involve posing a question to students and then encouraging them to work on solutions either individually or in small teams. The faculty member circulates and answers questions while also prodding students who are not making progress. Many students brought concept maps with them to class after they were introduced and used them during these activities to search out connections that would enable them to solve problems.

In a prior year when concept maps were used in the sophomore class, one student went on to form a small group that organized their own concept map for another core course known locally as being extremely challenging with a high attrition rate. The student, who was a solid B student, and his team went on to receive the highest scores on the exams through their preparation of concept maps. They felt it was this outside connection drawing that enabled them to move to the level that was being tested in that subsequent course.

Similar to the sophomore class, juniors and seniors often referred to the concept maps when discussing which concepts were eligible for coverage on upcoming exams. These discussions would start with a list of course objectives and what was fair game and students naturally moved the discussion on their own to the concept map, often then asking questions about how the material was fundamentally linked together.

Future work should be done to more quantifiably measure how learning styles and the use of concept maps helps or hinders different subsections of student populations succeed in engineering problem solving. This would involve the students taking a diagnostic test that identified their learning style while then controlling access to, or training in how to use, concept maps. It would also be an interesting study to quantify changes in student attrition rates over
time to see if concept maps may enable those students who normally would have left engineering to succeed.

Conclusion

This work discussed how concept maps have been used in many different disciplines, often with a subsequent raising of student performance as assessed through exams or other measures. An exploration of the use of concept maps showed that they had not previously been used during the problem solving process in order to reveal connectivity of topics to students. This work showed both traditional uses of concept maps and this new idea of using them to foster problem solving skills in the context of core chemical engineering courses. While student increases in performance were not measured in this work, the groundwork has now been laid for evaluating how integration of concept maps into curricula improves student performance in problem solving and problem syntheses tasks while possibly impacting student retention rates.

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Biographical Sketch
Paul Blowers received his PhD from UIUC in 1999 and has been a professor in chemical and environmental engineering at the University of Arizona since that time. He has been recognized as a top educator at the departmental and regional levels and in the past year was recognized as the best faculty academic advisor at his institution. He then went on to be selected as one of the top four faculty advisors in the U.S. by the National Association of Academic Advisors.
Distance Learning and Cognitive Load Theory to Enhance Computer Programming for Mechanical Engineers: Qualitative Assessment

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ABSTRACT

A computer programming class for students of mechanical engineering was re-designed with regard to both content and delivery. The goal was to improve student learning attitudes. Cognitive Load Theory (CLT) was used to re-design the content; on-line technologies were used to re-design the delivery. Since the targeted students were not computer scientists, the course was re-designed to focus on computer programming examples used in mechanical engineering. Scaffolding was used to integrate syntax elements with each other, algorithms with each other, and, the algorithm to the syntax. The effort was assessed using student attitudinal data. The effort confirmed the utility of CLT in course design, and it demonstrated that hybrid/distance learning is not merely a tool of convenience, but one, which, used purposefully, inspires students to learn.

Introduction

Cognitive Load Theory (CLT) provides guidelines to present information in a manner that encourages learning and optimizes intellectual performance [1]. As an example, consider the obstacles in learning new material in a non-native language. Clearly, there is an overload: learners must master the new material and the language itself. Interestingly, this is resonant with the challenge of learning to program a computer (learners must master operating systems and the syntax) for students not in the computer science major. CLT can mitigate challenges in such cases when learning loads are high. CLT was used to re-design a computer programming class for mechanical engineers at San Diego State University.

According to CLT, information can only be stored in long term memory after first being properly integrated, by working memory, into a mental structure that represents the schema of the material. However, the faculty of working memory has limits and this, unfortunately, can hinder learning, especially when many extraneous facts compete to challenge the cognitive learning loads (which, in the case of programming, encompass text editing, operating systems and compilers). CLT posits that there are three basic types of cognitive loads placed on a learner:

- “Intrinsic cognitive load” was first described in 1991 [2] as the essential material to be learned. Accordingly, all instruction has an inherent difficulty associated with it and
this intrinsic material may not be altered by an instructor. In learning a foreign language, this includes the vocabulary and syntax.

- “Extraneous cognitive load” is generated by the manner in which information is presented to learners [3] and, in the case of a programming language, the ancillary information such as text editors, compilers and operating systems. Or, in the case of a spoken language, the technologies such as language labs or voice recordings.
- “Germane cognitive load” was first described by Sweller, van Merrienboer, and Paas in 1998 [4]. It is that load devoted to the processing, construction and automation of schemata necessary to integrate knowledge into consciousness. This includes motivations to learn and how the knowledge is situated in the rest of the curriculum such as reading novels, or programming mathematical algorithms.

These three loads are additive in the learning process and research suggests [4] that when courses are redesigned with due respect paid to the interaction of cognitive loads, learning is improved. For example, while intrinsic load is generally thought to be immutable, instructional designers can exercise the option to manipulate extraneous and germane load. With complex material, it is best to strive to minimize the extraneous cognitive load and maximize the germane load.

**Table 1**
The Three Types of Cognitive Loads Placed on Learners of Computer Programming

<table>
<thead>
<tr>
<th>Load</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic</td>
<td>Syntax: data types, loops, logical tests, arrays, functions</td>
</tr>
<tr>
<td>Extraneous</td>
<td>The complex interplay between syntax, text editor and operating system</td>
</tr>
<tr>
<td>Germane</td>
<td>Numerical Algorithms in Computational Mechanics</td>
</tr>
</tbody>
</table>

Table 1 presents this author’s view of the various learning loads experienced in computer programming. The intrinsic learning load is high in computer programming. Thus, if one also employs methods that add an extraneous load (such as complex compiler interfaces), it is very likely that there will be little capacity left for germane load that might be used to motivate students of mechanical engineering to learn programming; and the ensuing overload would then hinder their learning.

Furthermore, it has been shown that complete, thorough, and fully commented programming examples provide greater motivation for novices than simply working out problems from scratch [5][6]. Although this may seem counterintuitive, tests have demonstrated that studying complete examples facilitates learning more than actually solving the equivalent problems [7]. Additionally, in many cases, a variation of worked examples balanced with assignments was used [8]. Students can be urged to complete the solution, which is only possible by the careful study of the partial example provided in the completion task. And like providing completely worked examples, this serves to decrease extraneous cognitive load [9].

Finally, the necessary ingredient to enhance the germane mode is through scaffolding. Scaffolding became an essential ingredient in this course re-design. And this approach is supported by existing research that has been successfully applied to the domain of computer programming [10].
2. Course prior to re-design

2.1 Course content

The course under discussion is SDSU: ME203 – Programming. In this class the C programming language is taught in a UNIX environment. The course presents a procedure oriented language (as opposed to object oriented language such as Java or C++), because mechanical engineers are more concerned with the process of applied mathematical algorithms (solids, fluids, thermal studies) than with objects to be manipulated (computer graphics, bioinformatics). Of the procedure oriented languages (e.g., C vs. FORTRAN), C was selected because it is the language in which most operating systems are written.

The focus of the class was on the syntax of the C language. Advanced syntax techniques such as ‘data structures’ were taught. Secondary attention was paid to the Gauss Reduction method and various algorithms to multiply matrices. Mechanical engineering coding examples were not integrated into the course; they were presented without instructional design forethought.

2.2 Course delivery

Prior to Fall 2006 the class met physically and the exclusive method of content delivery was through face to face lecture. Instruction was provided in a workstation laboratory. This laboratory was a dedicated computational resource cluster of 30 UltraSPARC models 170 and 170E workstations using the Sun Grid Engine software from Sun Microsystems. Each station in the cluster had 128MB of physical memory, and contained one 167MHz US-I CPU. The workstations were interconnected using high-speed network infrastructure from Myricom.

The instructor taught at one workstation and displayed his monitor on an overhead projector. Students were able to watch the instructor discuss the code line-by-line, compile it, and run it. Then, students would work on their own code in a separate lab session. This model of instruction had weaknesses. First, the size of the class was limited to the number of workstations. Furthermore, the workstations had to be upgraded every few years at considerable expense. Third, the students often expressed frustration as to why they were learning the material. Student reviews consistently mentioned that there was no reason for mechanical engineers to learn programming. Thus, course re-design was initiated.

3. Course after re-design

3.1 Course content

Two levels of course material were scaffolded by themselves and with each other: 1) the syntax of the language (data types, loops, logical tests, arrays and functions), and 2) the applied mathematical algorithms (vector, matrix manipulation, Gauss Reduction and Newton-Raphson methods). The purpose of the scaffolding was to avoid previous student criticisms of seeing no purpose to learning programming. The scaffolding more tightly connected the syntax to the algorithm and gave purpose to the class for mechanical engineers.
3.1.1 Vertical Scaffolding

The left column of Table 2 indicates the syntax structures that were discussed in the class. Complete and commented code syntax examples were scaffolded on the skeleton of preceding ones: loops were discussed in the context of logical structures, and arrays were discussed in the context of loops. The right column indicates the mathematical algorithms that were discussed in class: Complete and commented algorithms were scaffolded on previous ones. Thus, Newton-Raphson relied on the Gauss Reduction code; Gauss-Reduction relied on matrix manipulation and matrix manipulation relied on vectors. The same code “grew” and “evolved” in each example.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Syntax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Conversion</td>
<td>Data types and logic</td>
</tr>
<tr>
<td>Bisection Method</td>
<td>Logic &amp; loop formality</td>
</tr>
<tr>
<td>Newton’s Method</td>
<td>Logic &amp; loop formality</td>
</tr>
<tr>
<td>Numerical Integration</td>
<td>Logic &amp; loop formality</td>
</tr>
<tr>
<td>Repeat of all previous algorithms</td>
<td>Input/Output</td>
</tr>
<tr>
<td>Matrix-Vector Multiplication</td>
<td>Arrays</td>
</tr>
<tr>
<td>Gauss Reduction</td>
<td>Arrays, files</td>
</tr>
<tr>
<td>Gauss reduction with functions</td>
<td>Arrays, files functions</td>
</tr>
<tr>
<td>Newton Raphson Method</td>
<td>Arrays, files, functions, memory</td>
</tr>
</tbody>
</table>

3.1.2 Horizontal Scaffolding

The driving focus of the content in this class was the algorithm rather than the syntax. Thus, this inverts the way programming has traditionally been used in which syntax rules are presented and are the focus – as often happens when programming classes are farmed out to computer science departments. Furthermore, there were no coding examples of sorting, alphabetizing, or interest rate problems that plague introductory computer programming courses for mechanical engineers.

The instructional goal was to challenge the students to read codes as if they were a new language. It was not expected that the students master the code’s nuances and reproduce them at this stage. Rather, the goal is to immerse the students in a new language and expect them to follow the general idea of how the language implements the logic of a simple game.

Next, the course delved into a series of code examples involving matrix manipulations. And finally it moved on to the two core concepts of the course. In fact, students were often reminded that these two algorithms were the core algorithms in mechanics. The Gauss
Reduction is the algorithm to solve a system of linear equations, while Newton-Raphson is for a system of non-linear equations; both are critical components in mechanics-based Simulation Science. However, there is serendipitously something more profound which was exploited here: the Newton-Raphson method builds upon the Gauss Reduction method. This creates an overarching structure to the class as it drives toward the study of very simple non-linear systems.

3.1.3 Course Delivery

With regard to delivery, two modes were used in equal parts: 1) face to face, and 2) interactive, on-line application sharing. Half the classes were face-to-face, and this is where algorithm and syntax were taught. Extensive PowerPoint slides were developed and they were tied to each item in Table 2. Face-to-face lectures focused on the interplay of intrinsic and germane learning loads.

The extraneous learning load was obviated by use of on-line instructional technologies. However, this was not a passive use in which students simply observed lectures. Application sharing technology was used – the instructor took control of student laptops as if working with the student, side by side, while also demonstrating the effort to the rest of the class. The schematic for an on-line session is indicated Figure 1. Students were able to work on their assignments from home (during or after class lab-time), regardless of their operating system, by first establishing a terminal SSH session to the server on campus using a monitor prompt. Once connected to the server machine, students are able to write, compile, and debug their codes.

The instructor also maintained an SSH connection to the same server and exploited the application sharing interface of Wimba. The instructor shared his desktop (which contains an SSH connection to the server) with the class and demonstrated the process of writing, compiling, debugging, and running example codes. Occasionally, whether during a class session or during “office hours,” a particular student would request assistance with an assignment (indicated by the laptop with the “?” mark and his SSH connection by the largest black monitor window external to his laptop). At those times, the instructor activated the Wimba application sharing interface and asked the student to share his/her desktop with him and the rest of the class. Then, the
instructor addressed the student’s questions, while also sharing the information with all of the students.

Special note is made of the fact that all the students in the class used the same operating system on which to compile and run their code examples. This minimized a great deal of confusion for the students: they used an SSH tool to connect to the common server on which they all studied and learned. This summary warrants focused reiteration. Extraneous learning loads were lessened by on-line, desktop sharing; these learning experiences demonstrated code writing and compiling, interactively. The instructor, at home, used Wimba to pass through the workstation of the student (also at home) and continued on to the student’s account on the server (on campus), fixing the code and sharing the lesson with sixty other students (also at home). The instructor then archived the session, which enabled other students to play it back at their leisure. In this way, students were able to observe codes being written, edited and recompiled. Also, all the writing and compiling occurred in a common workstation environment, unencumbered by the nuances of diverse compilers. This consistency — this common computational environment — reduced the extraneous load of learning operating systems, compilers and text editors; students were able to focus attention on the syntax of the language and the mathematical algorithms.

4. **Attitudinal Assessment**

This course was subjected to qualitative student reviews. The same instructor has taught this class for ten years; thus, any improvement in assessment that resulted from the re-design cannot be attributed to recent mastery of the material. Two assessment periods are provided. Fall, 2006 assessments were for the class before there was any re-design. Spring, 2008 represents the first semester in which the instructor gained facility with the instructional technology and the modified curriculum.

Students were asked to respond to this question: *What are your comments/suggestions for the course?* Naturally, this paper cannot provide all responses, so random responses were selected from the fall, 2006 semester and are presented in Table 3. Responses from the spring, 2008 semester are presented in Table 4.

| Fall, 2006 Responses to Qualitative Questions Concerning the Course |
|---|---|
| hard to understand |
| For a course that is comparable to learning a foreign language in a matter of 15 weeks, not only was it hard to adapt to but the professor made it even more difficult by making it hard to ask questions. |
| Try to make subject more interesting |
| It seems to be an unnecessary class for mechanical engineers |

The previous responses were mostly negative and the few positive responses were apathetic. After the re-design, the negative responses became more active in suggesting improvements while the percentage of positive responses increased and became more vigorous.
Table 4
Spring, 2008 Responses to Qualitative Questions Concerning the Course

| Comment |
|------------------|------------------|
| More examples of real world application, shorter classes, keep this direction going! | |
| i felt that this course didn't teach me how to write programs only a few key algorithms. I feel that the course should be more focused on the coding and not the algorithms | |
| NO MORE ONLINE CLASSES, I PAY MY TUITION TO LEARN FROM A HUMAN NOT A COMPUTER!!!!!!!!!!! | |
| This is an excellent introductory course in programming for any non computer engineering student. I think the structure of the exams should be changed; I think the exams should be more like project-oriented. | |
| This is a great course overall, but there has to be a class before this at least to show us how programming works; to teach us the basics of programming and getting familiar with it. This course just jumps ahead and you can fall back very easily. | |
| go a little slower in the beginning, since that's the most important part | |

Clearly, this re-design has excited the students. Enrollment has increased. Students took a more active part in their learning. They offer advice on how to improve the class, and, this, in turn, makes it easier to continually improve the course through consistent re-design.

Students were then asked to respond to this question: What are your comments, positive or negative, on the instructor's teaching? Again, random responses were selected from the fall 2006 semester and are presented in Table 5. Responses from the spring, 2008 semester are presented in Table 6.

Table 5
Fall, 2006 Responses to Qualitative Questions Concerning the Instructor

<table>
<thead>
<tr>
<th>Comment</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. I came off as the least approachable professor i ever had causing communication problems which led to a tear in his teacher/student relationship.</td>
<td></td>
</tr>
<tr>
<td>Moves much to fast through the course material. Maybe it's because there is too much material for the course, but it needs to be slowed down.</td>
<td></td>
</tr>
<tr>
<td>I wish he would explain what he is doing a little more clearly. He can breeze right through an area expecting us to know what he is talking about.</td>
<td></td>
</tr>
<tr>
<td>Answer peoples questions with out making them think that they are stupid. Usually people who are in engineering are not stupid so treat them with respect.</td>
<td></td>
</tr>
<tr>
<td>Teacher was not able to stimulate interest. Unable to fully/clearly explain the material.</td>
<td></td>
</tr>
<tr>
<td>negative, everything i learned was from the internet</td>
<td></td>
</tr>
</tbody>
</table>

Table 6
Spring, 2008 Responses to Qualitative Questions Concerning the Instructor

<table>
<thead>
<tr>
<th>Comment</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>He moves a little fast but if you ask him to slow down he will. You can ask any question no matte how dumb and he will answer it over and over again until you get it. Very helpful</td>
<td></td>
</tr>
<tr>
<td>He goes out of his way to keep students active in the class which is rare in a teacher.</td>
<td></td>
</tr>
<tr>
<td>Very helpful teacher and clearly taught the material</td>
<td></td>
</tr>
<tr>
<td>Instructor goes above and beyond the call of duty.</td>
<td></td>
</tr>
<tr>
<td>The instructor was always available for the students and was very flexible about helping out students.</td>
<td></td>
</tr>
<tr>
<td>Dr. Impelluso is the most accessible, straightforward, fair teacher that I have ever had in my life. He fully employs every method possible to teach us, including blackboard, a separate class website, wimba 'liveclassroom' and archives, powerpoint and word outlines, emails on a regular basis, in-classroom instruction, and was even very active on the discussion board. I do not doubt that he spent more time on this class than I did on all of my classes combined. He made every effort (and I mean every) to keep his grading scheme fair. If a single person expressed their confusion with a topic, he made it a point to comprehensively review the topic during the following class. I feel like I learned a lot about what the next steps in programming and engineering look like, and am very interested to continue to pursue these fields</td>
<td></td>
</tr>
</tbody>
</table>

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as a career.

Dr. Impelluso extends himself above and beyond to help his students. However, his lectures seem to change focus abruptly which leaves the student lost.

The vocabulary for the course makes it difficult to ask questions. It is new so I didn't know how to formulate questions and Impelluso is not aware or not sensitive enough to this. I really like the fast response time in email. I really appreciated the extra time and effort and caring about students that he put into this class. Impelluso stressed too much on how students were doing and made himself too available to students, resulting in him stressing and getting upset. I suggest setting up office hours but holding them online or by individual appointment only and make help more the students responsibility. Good teacher. I love it when teachers care, it helps and motivates, so thank you, overall I give you an above average for teaching, most don't care, especially those with tenure, is that how you spell it? Thanks!!

5. Discussion

5.1 Cost Savings

As a result of this new foray into distance learning, the workstation cluster once used to instruct the class in exclusive face-to-face lectures is no longer needed. This has already amounted to nearly $40,000 in savings to the department. Furthermore, the distance delivery has enabled the class to overcome the enrollment limitation dictated by the available workstations. Enrollment has progressed from under 30 students to now over ninety in one session, obviating the need to hire a lecturer to support additional sections. As of this writing, the original laboratory has been removed and the space is now utilized for other classrooms.

5.2 Plateau Instruction

The author of this paper engaged students in several personal discussions about their learning experiences and these are summarized herein. This section is entirely anecdotal, very personal, and without reference to the literature. It reports on feelings and thoughts expressed by students.

It seems that students are able to approach their high school studies in a disintegrated way. Consider Biology: the material and the textbooks are cleanly segregated; information is sequentially presented on the digestive system, the cardiac system, the muscular system, the nervous system, and the skeletal system. Students are quite capable, they tell the author, of mastering one system, failing another, and still securing high grades in the end. The same can happen in high school literature classes (authors are disintegrated), and physics (kinematics, thermal studies, optics, and nuclear studies).

Many of the students verbally shared their feelings that they never expected the course to stack the way it did and they attributed this to their poor performance. And this justified the introduction of the two mid-semester review periods conducted in the class. The instructor stopped all progress in the class and reviewed all material. Rather than consider this a simple review period, placing an onerous burden upon the instructor, the instructor now considered this to be a “plateau” experience, wherein no new material was presented. This enabled students who underestimated the course to catch up and not suffer penalty.
5.3 On-Line for a purpose

SDSU has a policy that a course is “hybrid” if 45% of instruction occurs on-line. This compelled the course designer to initially hold physical sessions (55%) and on-line sessions (45%) indiscriminately and one after the other. In the second roll-out, however, the instructor began using the on-line sessions for laboratories to diminish extraneous load. The author advises adopters of distance learning to seek out which aspects of a course are suitable for distance learning and deploy those first.

6. Conclusions

Distance technologies have changed since they first emerged – they are no longer passive technologies which simply enable download of content; they now enable interactive learning. This course re-design made have use of these latest technologies, specifically including desktop sharing. The redesign was guided by CLT. CLT has been demonstrated to be a useful schema for re-designing a course. Three types of scaffolding have been deployed: vertical and horizontal (scaffolding intrinsic learning loads) and temporal (scaffolding germane learning loads). Distance technologies were used to minimize extraneous learning loads.

The re-design resulted in a tremendous cost savings to the department. Student perceptions and motivations have dramatically increased. It is noted that that author chose to use increasingly more difficult exams to ensure equity in grading and to prevent grade inflation. In future work, the author will shortly revert back to exams from years past and report on the results. It is expected, however, that the majority of the students will excel.

Can this design and implementation impact other classes in mechanical engineering; specifically, in courses which teach programming interfaces such Computer Aided Design software? Yes, provided that an aspect of SSH is addressed. The difficulty with SSH is that it is text-based: a graphics application running on a remote server cannot be displayed on the local “student” client. X-Win, however, enables graphics codes to be displayed remotely. X-Win32 is StarNet’s latest X terminal application for Windows and Mac clients. X-Win32 allows Windows users to connect to Linux/Unix servers on a network and run the applications from those servers on their Windows desktop. This spring (2009), Xwin-32 will be deployed in the class so that students can instantiate a simple graphics code.

This has further implications for distance learning in engineering, for it will enable universities to exit the computer infrastructure support business. Universities can load visualization software on a server, enable the students to download XWin, and run the codes on the server, yet display them at home. Advanced visualization tools can now be fully deployed in all aspects of a curriculum, while still using distance learning tools. For once, universities can exit the hardware infrastructure support business and go so far as to invert pedagogies by exploiting 3D simulations with distance learning in all aspects of a curriculum.
REFERENCES


BIOGRAPHICAL SKETCH

Dr. Impelluso received his BA in Liberal Arts from Columbia University. This was followed by two MS degrees in Civil Engineering and Biomechanics, also from Columbia. He received his doctorate in Computational Mechanics from the University of California, San Diego. Following this, he worked for three years in the software industry, writing code for seismic data acquisition, visualization, and analysis. He then commenced post-doctoral studies at UCSD, wherein he secured grants in physics-based virtual reality. He is now a tenured associate professor at San Diego State University, revisiting and researching human bone remodeling algorithms and muscle models using advanced tools of the cyberinfrastructure. He has created a curriculum in which students learn mechanics not by using commercial simulation software, but by creating their own. His interests include opera, sociology, and philosophy. He is currently enjoying teaching his two young children how to ride bicycles.

FUNDING AND SUPPORT

(This work was supported by two grants.)

*Multi-Phase Mechanics*

| Agency: NSF |
| Amount: $124,550 |
| Duration: 11/05—11/06 (plus one year no-cost extension) |
| Summary: Extend a platform for solution of multi-phase problems by incorporating non-linear interaction and contact with extension year duties of curricular deployment. |

*Dissemination of a New Mechanical Engineering Curriculum*

| Agency: FIPSE |
| Amount: $370,000 |
| Duration: 9/20—9/05 (plus two year no-cost extension) |
| Summary: This project funded the evolution and dissemination of a method to teach mechanical engineering at its intersection with computer science. |

ACKNOWLEDGEMENTS

The author thanks Suzanne Aurilio and SDSU’s pICT for providing valuable assistance with this course re-design.
A Junior Level FPGA Course in Digital Design
Using Verilog HDL and Altera DE-2 Board
For Engineering Technology Students

by

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California Polytechnic University
Pomona, California

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Abstract

This FPGA course is designed for junior level students who are pursuing a baccalaureate degree in electronics and computer engineering technology. Exercises were adapted for use of the Altera DE-2\(^6\) development board, which were donated by Altera cooperation. Software used was Quartus II, which is freely available from Altera website. The board was found to be useful and student-friendly for majority of the laboratory exercises and for simple design projects.

Introduction

Use of a hardware description language, such as VHDL or Verilog to program a programmable logic device, has become very common basis for digital design laboratories. The programmable logic devices themselves have become capable of handling greatly increased amounts of logic, allowing more and more complex design to be programmed into more and more affordable logic devices. These programmable devices are capable of handling many inputs and can produce several outputs. The course, which was taught, was based on both combinational and sequential logic design.

Software Installation on PC\(^1,6\)

The Quartus II software is freely available from Altea website, for the laboratory use a license was acquired through Altera university education division. Following are the steps to download software from Altera website:

- Go to Altera website and click on software download
- Click on Quartus II Web Edition\(^1\) Software
- In order to successfully download, fill out the form submit the request for downloading
- Once the form is filled out, it should lead to the download manager page. From there determine where you want to save the installation file.
- Once the download is complete, launch the Quartus software and follow the steps provided from the wizard
- After the software has been is installed successfully, a license file is required to run. This license file could be obtained from Altera website\(^7\). To install this file follow these steps:

1. Go to start ⇒ Run
2. Type cmd or command
3. Type ipconfig/all
4. Write MAC address of the Ethernet adapter
5. Go to Altera site and click on licensing and follow the steps
6. A license file will be e-mailed to you
7. Save that file in Quartus folder
8. Now you are ready to use Quartus software
Designing Combinational and Sequential Circuits

The Quartus II software provides three options for designing circuits:

- Schematic capture
- Using VHDL
- Using Verilog HDL

For this course, Verilog HDL was used to design logic circuits. Detailed instructions were provided to students about creating source files, using Altera DE-2® board, compiling source file, making pin assignments for Cyclone II EPC35F672C6 device, and downloading compiled file to the Altera DE-2 board.

FPGA Structure

<table>
<thead>
<tr>
<th>Year</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology feature size</td>
<td>78 nm</td>
<td>68 nm</td>
<td>59 nm</td>
<td>52 nm</td>
<td>45 nm</td>
<td>36 nm</td>
</tr>
<tr>
<td>Transistors per cm²</td>
<td>283 M</td>
<td>357 M</td>
<td>449 M</td>
<td>566 M</td>
<td>714 M</td>
<td>1,133 M</td>
</tr>
<tr>
<td>Transistors per chip</td>
<td>2,430 M</td>
<td>3,061 M</td>
<td>3,857 M</td>
<td>4,859 M</td>
<td>6,122 M</td>
<td>9,718 M</td>
</tr>
</tbody>
</table>

Fig 1: Silicon Wafer

Fig 2: Silicon Technology Evolution

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Fig 3: Internal Structure of a Programmed FPGA
Fig 4: A Generic Design Flowchart

Design

DESIGN ENTRY
Schematic
Verilog

Synthesi

Functional simulation

No

Design

Yes

Physical

Timing

No

Timing requirements

Chip
Fig 5: A Simple Simulation Test Using Schematic Capture
Simple Combinational Design Verilog Code for k-bit 2x1 Mux and k-bit Adder

```verilog
// k-bit 2-to-1 multiplexer
module mux2to1 (V, W, SelM, F);
    parameter k = 8;
    input [k-1:0] V, W;
    input SelM;
    output [k-1:0] F;
    reg [k-1:0] F;

    always @(V or W or SelM)
        if (SelM == 0) F = V;
        else F = W;
endmodule

// k-bit adder
module adderk (carryin, X, Y, S, carryout);
    parameter k = 8;
    input [k-1:0] X, Y;
    input carryin;
    output [k-1:0] S;
    output carryout;
    reg [k-1:0] S;
    reg carryout;

    always @(X or Y or carryin)
        {carryout, S} = X + Y + carryin;
endmodule
```

Fig 6: A Typical Simulation Result of Test Run Using Verilog\(^5\)

![Simulation Waveforms](image-url)
Sequential Circuit Code For 2-bit BCD Counter
Verilog Code

module BCDcount (Clock, Clear, E, BCD1, BCD0);
  input Clock, Clear, E;
  output reg [3:0] BCD1, BCD0;

  always @(posedge Clock)
  begin
    if (Clear)
      begin
        BCD1 <= 0;
        BCD0 <= 0;
      end
    else if (E)
      if (BCD0 == 4'b1001)
        begin
          BCD0 <= 0;
          if (BCD1 == 4'b1001)
            BCD1 <= 0;
          else
            BCD1 <= BCD1 + 1;
        end
      else
        BCD0 <= BCD0 + 1;
  end
endmodule

Laboratory Experiments

1. Introduction to Quartus II\textsuperscript{6} software
2. Introduction to combinational logic and Verilog
3. Multiplexes and Decoders
4. Introduction to Flip-Flops
5. Counters
6. State Machine Design\textsuperscript{2}
7. Projects
Conclusions

The FPGA course was successfully taught and provided students with good basic knowledge of Verilog HDL. The Altea DE-26 board is user friendly and students had no problems using it. In the future more complex projects will be assigned to students using faster clocks and LCD display, which are on board features. This course will be made a required core course in the future, which will follow combinational logic and sequential logic courses. I had inquires from several companies who are looking for students with FPGA design experience. I think this course fits very well in Electronics and Computer Engineering Technology curriculum.

References


Biography

Tariq Qayyum graduated from University of Engineering and Technology Lahore, Pakistan with BSEE degree in 1978 and with MSEE degree from Rochester Institute of Technology, Rochester New York in 1982. He has been teaching at Cal Poly Pomona since 1986. His interest includes digital design, microprocessors, and programming languages.
DESIGN, FABRICATION, AND ANALYSIS OF PHOTODYNAMIC THERAPY OXYGEN MONITORING SYSTEM FOR USE IN ESOPHAGEAL CARCINOMA

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Abstract
Photodynamic therapy (PDT) is an effective and minimally invasive treatment modality with relatively fewer side effects than chemotherapy and radiation, which has been approved by the FDA for treatment of esophageal cancer. Maximum therapeutic outcome of the PDT protocol for each individual patient requires optimization of the components of PDT operating at their highest efficacy. Tumor necrosis, the method of malignant tissue destruction by PDT, is carried out by the toxic singlet oxygen molecules that are being formed from the molecular oxygen in the tumor. The availability of molecular oxygen, being the rate limiting step for PDT, plays a key role in the treatment protocol. Currently, the PDT of esophageal carcinoma is a relatively blind process since there is no method to monitor the tumor oxygen level during the treatment. In this paper, we present an optical technique to monitor molecular oxygen level in the PDT milieu. The method described herein is a reflection oximetry technique designed with small semiconductor lasers and a silicon photodiode. The light used for monitoring system comes from two semiconductor diode lasers of 650 nm and 940 nm wavelengths. The two lasers and the photodiode are integrated into a small package which is then mounted onto a balloon catheter containing the PDT light delivery system. The lasers and photodiode are powered and controlled by a control box that is connected via a cable. The light sources and the photodiode output are controlled by LabVIEW virtual instrumentation. The sequential on and off light sources and the respective reflective signals are processed with MATLAB. The latter code integrates with LabVIEW to make an automatic calculation of the corresponding light absorption by each chromophore to determine the change in oxygen level as well as the amount of blood and oxygen present in the treatment area. The designed system is capable of monitoring the change in oxygen level and the blood flow in any part of the human body where it is possible to place the package.

Key words: Photodynamic therapy, esophageal carcinoma, oxygen detection, photonic reflective oximeter
1. Introduction

Oxygen is a key element in PDT and would deplete with time\(^1\). Oxygen and photosensitizer level monitoring during PDT are effective ways of maintaining the optimum concentrations of this rate limiting substance throughout the treatment process. The photo bleaching of photosensitizer is also considerable during PDT. Preferably, such information should be available to clinicians on a continuous basis rather than at the beginning and at the end of the treatment. This requirement can be met non-invasively with the technology of optical detection. The optical techniques are now well established and are in regular clinical use during anesthesia and intensive care when monitoring patient vitals.

An oximeter is a commonly used biomedical instrument to detect the oxygen content in capillaries\(^2,3-11\). Pulse oximeters are commonly used instruments for \textit{in-vivo} reading\(^12,13-14\). While this is not a perfect method to read the true arterial oxygen saturation of human tissues, its principle can be used to measure the relative oxygen concentration in a tumor during PDT\(^15\). The physics behind this technique is based on the light absorption of the two different types of hemoglobin, oxyhemoglobin (Hbo\(_2\)) and deoxyhemoglobin (Hb), in the blood stream. This work discusses the integration of an optical detection system into the PDT balloon catheter using an integrated system of detector and lasers to monitor the oxygen level and the photosensitizer concentration. Light transmitted through a tissue is detected and the portion of absorbed energy is calculated to analyze the oxygen content. Light transmitted through a chromophore is given by the Beer-Lambert equation\(^13\).

The change in blood chromophores in the tissue can be modeled with the modified Beer-Lambert law. When the light source and the detector are located on a tissue the detector receives backscattered light. The amplitude of the light that the detector receives can be very much less, compared to the light emitted by the source, due to scattering and absorption by the tissue. Therefore, usage of high power light sources and efficient detectors to measure the backscattered light are very important in a detection system.

2. Theory of reflectance optical detection system

The physical requirement necessary for an optical system in order to detect multiple numbers of chromopores is to have light sources of specific wavelength with different absorptivity pattern. The light attenuation between the source and the detector can be written as follows:

\[
- \log_{10} \left( \frac{I_{\text{out}}}{I_{\text{in}}} \right) = OD_\lambda
\]

where \( I_{\text{in}} \) is the incident light, \( I_{\text{out}} \) is the detected light, and \( OD_\lambda \) is the optical density for wavelength \( \lambda \). Optical density is a function of absorption \( (A_\lambda) \) and scattering \( (S_\lambda) \) of wavelength \( \lambda \). Therefore, Eq.(2) can be rewritten as follows:

\[
- \log_{10} \left( \frac{I_{\text{out}}}{I_{\text{in}}} \right) = OD_\lambda = \text{attenuation} = A_\lambda + S_\lambda
\]

\( \text{HbO}_2, \text{Hb} \), and the photosensitizer (PS) are the main absorber chromophores in the PDT environment. Therefore, the light absorption can be written as follows:
\[
A_\lambda = \epsilon_{\text{HbO}_2,\lambda} C_{\text{HbO}_2} L_\lambda + \epsilon_{\text{Hb},\lambda} C_{\text{Hb}} L_\lambda + \epsilon_{\text{PS},\lambda} C_{\text{PS}} L_\lambda
\]

where \(\epsilon_{\text{HbO}_2,\lambda}\), \(\epsilon_{\text{Hb},\lambda}\), and \(\epsilon_{\text{PS},\lambda}\) are the specific extinction coefficient of oxyhemoglobin, deoxyhemoglobin and photosensitizing agent for wavelength \(\lambda\). \(C_{\text{HbO}_2}\), \(C_{\text{Hb}}\), and \(C_{\text{PS}}\) are the concentrations of the oxyhemoglobin (HbO2), deoxyhemoglobin (Hb) and photosensitizing agent respectively, and \(L_\lambda\) is the optical path length. This optical path length can be expressed as source detector separation,

\[
L_\lambda = d \cdot DPF_\lambda
\]

where \(d\) is the separation between the light source and the detector and \(DPF_\lambda\) is the differential path length factor. The correction for the mean photon path length for scattering, is termed the differential pathlength factor, and expressed as follows\(^{16}\):

\[
DPF_\lambda = \frac{1}{2} \left( \frac{3 \mu_s^f}{\mu_a^r} \right)^{1/2} \left[ 1 - \frac{1}{1 + d \cdot (3 \mu_s^f / \mu_a^r)^{1/2}} \right]
\]

where \(\mu_a^r\) is the absorption coefficient and \(\mu_s^f\) is the reduced scattering coefficient at wavelength \(\lambda\). Consumption of oxygen in blood, during the PDT reaction, leads to reduction in oxyhemoglobin concentration. Therefore the optical density \(OD_\lambda\), varies with time. This differential \(OD_\lambda\) value can be written as follows:

\[
\Delta OD_\lambda = OD_{\lambda,\text{final}} - OD_{\lambda,\text{initial}} = d \cdot DPF_\lambda (\epsilon_{\text{HbO}_2,\lambda} \Delta C_{\text{HbO}_2} + \epsilon_{\text{Hb},\lambda} \Delta C_{\text{Hb}} + \epsilon_{\text{PS},\lambda} \Delta C_{\text{PS}})
\]

Thereafter the effect of scattering is not influential to the model. Each chromophore has a specific extinction coefficient and a differential pathlength factor. Therefore, measurements with the three wavelengths give

\[
\Delta OD_{\lambda_1} = d \cdot DPF_{\lambda_1} (\epsilon_{\text{HbO}_2,\lambda_1} \Delta C_{\text{HbO}_2} + \epsilon_{\text{Hb},\lambda_1} \Delta C_{\text{Hb}} + \epsilon_{\text{PS},\lambda_1} \Delta C_{\text{PS}})
\]

\[
\Delta OD_{\lambda_2} = d \cdot DPF_{\lambda_2} (\epsilon_{\text{HbO}_2,\lambda_2} \Delta C_{\text{HbO}_2} + \epsilon_{\text{Hb},\lambda_2} \Delta C_{\text{Hb}} + \epsilon_{\text{PS},\lambda_2} \Delta C_{\text{PS}})
\]

\[
\Delta OD_{\lambda_3} = d \cdot DPF_{\lambda_3} (\epsilon_{\text{HbO}_2,\lambda_3} \Delta C_{\text{HbO}_2} + \epsilon_{\text{Hb},\lambda_3} \Delta C_{\text{Hb}} + \epsilon_{\text{PS},\lambda_3} \Delta C_{\text{PS}})
\]

Solving Eq.(7), Eq.(8) and Eq.(9) we obtain the general equations for three different chromophores in blood, \(\Delta C_{\text{HbO}_2}\), \(\Delta C_{\text{Hb}}\), and \(\Delta C_{\text{PS}}\):
\[ \Delta C_{HbO_2} = \frac{\Delta OD_{\lambda_1} \cdot DPF_{\lambda_1} \cdot DPF_{\lambda_2} \cdot (e_{PS,\lambda_1}e_{Hb,\lambda_2} - e_{Hb,\lambda_1}e_{PS,\lambda_2})}{a_1} + \]

\[ \frac{\Delta OD_{\lambda_1} \cdot DPF_{\lambda_1} \cdot DPF_{\lambda_2} \cdot (e_{Hb,\lambda_1}e_{PS,\lambda_2} - e_{PS,\lambda_1}e_{Hb,\lambda_2})}{a_1} + \]

\[ \frac{\Delta OD_{\lambda_1} \cdot DPF_{\lambda_2} \cdot DPF_{\lambda_3} \cdot (e_{PS,\lambda_2}e_{Hb,\lambda_3} - e_{Hb,\lambda_2}e_{PS,\lambda_3})}{a_1} \] (10)

\[ \Delta C_Hb = \frac{\Delta OD_{\lambda_1} \cdot DPF_{\lambda_1} \cdot DPF_{\lambda_2} \cdot (e_{HbO_2,\lambda_1}e_{Hb,\lambda_2} - e_{PS,\lambda_1}e_{HbO_2,\lambda_2})}{a_1} + \]

\[ \frac{\Delta OD_{\lambda_1} \cdot DPF_{\lambda_1} \cdot DPF_{\lambda_2} \cdot (e_{PS,\lambda_1}e_{HbO_2,\lambda_2} - e_{HbO_2,\lambda_1}e_{PS,\lambda_2})}{a_1} + \]

\[ \frac{\Delta OD_{\lambda_1} \cdot DPF_{\lambda_2} \cdot DPF_{\lambda_3} \cdot (e_{Hb,\lambda_2}e_{PS,\lambda_3} - e_{PS,\lambda_2}e_{HbO_2,\lambda_3})}{a_1} \] (11)

\[ \Delta C_{PS} = \frac{\Delta OD_{\lambda_1} \cdot DPF_{\lambda_1} \cdot DPF_{\lambda_2} \cdot (e_{HbO_2,\lambda_1}e_{Hb,\lambda_2} - e_{Hb,\lambda_1}e_{HbO_2,\lambda_2})}{a_1} + \]

\[ \frac{\Delta OD_{\lambda_1} \cdot DPF_{\lambda_1} \cdot DPF_{\lambda_2} \cdot (e_{HbO_2,\lambda_1}e_{Hb,\lambda_2} - e_{Hb,\lambda_1}e_{HbO_2,\lambda_2})}{a_1} + \]

\[ \frac{\Delta OD_{\lambda_1} \cdot DPF_{\lambda_2} \cdot DPF_{\lambda_3} \cdot (e_{HbO_2,\lambda_2}e_{PS,\lambda_3} - e_{PS,\lambda_2}e_{HbO_2,\lambda_3})}{a_1} \] (12)

where

\[ a_1 = DPF_{\lambda_1} \cdot DPF_{\lambda_2} \cdot DPF_{\lambda_3} \cdot d(e_{PS,\lambda_1}e_{Hb,\lambda_2}e_{HbO_2,\lambda_3} + e_{HbO_2,\lambda_1}e_{PS,\lambda_2}e_{Hb,\lambda_3} + e_{Hb,\lambda_1}e_{Hb,\lambda_2}e_{PS,\lambda_3} \]

\[ - e_{Hb,\lambda_1}e_{PS,\lambda_2}e_{HbO_2,\lambda_3} - e_{PS,\lambda_1}e_{HbO_2,\lambda_2}e_{Hb,\lambda_3} - e_{HbO_2,\lambda_1}e_{PS,\lambda_2}e_{Hb,\lambda_3}) \]

The change in oxygen level and photosensitizer level is given as follows:

\[ \Delta OXY = OXY_{t_1} - OXY_{t_2} \] (13)

\[ \Delta PS = PS_{t_1} - PS_{t_2} \] (14)

where \( OXY \) and \( BV \) are oxyhemoglobin and blood volume changes:

\[ OXY = \Delta C_{HbO_2} - \Delta C_{Hb} \] (15)

and

\[ BV = \Delta C_{HbO_2} + \Delta C_{Hb} \] (16)

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Therefore, a system with two different light sources and a light detector can evaluate the intensity of the incident light and the detected reflected light and thereby calculate the concentration of hemoglobin and oxyhemoglobin.

### 3. The system design

As explained previously there should be at least three different wavelengths to monitor the blood chromophore level and the photosensitizing agents. Many number of light sources from each wavelength, and many number of detectors can be used for this purpose. However increasing the number of devices complicates the probe geometry. The proposed detection system design consists of three semiconductor lasers for the excitation of the chromophores and a detector. In the device fabrication we include two light sources and a photodetector packaged together as shown in Fig.1.

![Fig.1: (a) Oxygen detection system in the presence of blood chromophore; (b) circuit for lasers and the detector; (c) encapsulated cross section with lens; and (d) system design to insert into the balloon catheter.](image)

The prototype development and the testing could be performed with any type of photosensitizing agent. The locations of the light sources are determined by the light scattering distance of living tissue. In this work, a center-to-center distance of a light source and the detector is kept at 1cm. This distance provides sufficient spacing for the prototype fabrication and also for the detector to receive enough photons to give an appropriate signal output. The power supply, control system, and data acquisition system are connected to the insertable package. Figure 1 shows a diagram of the insertable part of the detection system.

The ideal probe to be used for PDT of esophageal carcinoma will have the following special features. The lasers and the photodetector are packaged onto a printed circuit sub-mount for miniaturization. The package is then encapsulated in a perfectly amorphous polymer to prevent

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the circuitry from damage during operation (Fig.1(c)). A concave lens is integrated onto the photodiode to collect maximum reflected light, as shown in Fig.1(c). The packaged lasers and the photodetector are connected to a flexible steel cable (Fig.1(d)), so that the entire detection unit can be moved inside the balloon catheter to the precise location of the tumor. Figure 2 gives a block diagram of the oxygen detection system. The oxygen detection system would be calibrated and validated using a commercially available oxygen detection system. This system is designed without an advanced laser driver; it uses a less expensive DC power supply or a 12V battery. The selection of the power supply is based on the power requirement of the semiconductor lasers and the detector bias voltage.

![Fig.2: Schematic of the oxygen detection system.](image)

**3.1 Selection of the exciting light wavelength**

Certain wavelengths transmitted, through a photosensitizing agent accumulated tissue, is absorbed by the photosensitizing agent and the agent will fluoresce upon onset of a light. The fluorescence intensity is dependent on the amount of oxygen in a tumor. A normal tissue has more oxy-hemoglobin and hence more oxygen. Fluorescence spectrum of the photosensitizing agent (Photofrin) accumulated tumor and normal tissue is shown in Fig.3. The fluorescence spectrum clearly shows the fluorescence intensity difference in the tumor and the normal tissue at a range of wavelengths. Also, as seen in Fig.3, at certain wavelengths, higher than 750 nm wavelengths, there is no difference in fluorescence spectrum by the photosensitizing agent of the tumor and the normal tissue.

The largest difference between the tumor and the normal tissue fluorescence for the Photofrin photosensitizer lies between 650nm to 675nm (Region1 in Fig. 3). The wavelengths on or above 750 nm, infrared (IR) Region 2 in Fig. 3, shows no difference in the fluorescence spectrum of the tumor and the normal tissue. Therefore, in the selection of the wavelengths the first laser is selected with 650nm and the other with 904 nm. These two selections provide a better spectral heterogeneity for the oxygen detection. Semiconductor lasers of these wavelengths are commercially available at reasonable prices.

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The typical operating voltage of the 650nm semiconductor laser selected for the application is 2.3V and the maximum voltage is 2.6V. The recommended operating voltage for 904nm laser is 1.8V to 2.5V, and the suggested typical voltage is 2.0V. The operating temperature range of the 650nm laser is -10 to 70°C and for the 904nm laser is -10 to +50°C. These operating temperatures are adequate to drive the lasers in a low duty cycle without degrading the lasers.

3.2 Detector selection

The light detector is selected to sense the backscattered light of 650nm and 940nm. A commercially available silicon photodiode with a spectral response of 350-1100 nm is used for the package to detect the range of light (including detection of the fluorescence of a photosensitizer). The rise and fall times of the photodiode are both 10ns at 20V bias voltage with a 50Ω load. This is, therefore, well suited for this application since the current saturation does not interfere with the light emitting sequence. The active area of this detector is 13mm² and the detector is packaged in a standard T05 (0.36”) submount. This packaged detector is used only for the prototype design. In an actual device fabrication, the detector and the lasers could be imprinted onto a balloon catheter for smaller size devices.

4. Control system layout and oxygen monitoring technique

The two lasers in the probe are driven by a simple DC power supply. Duty cycles of the lasers are determined by the detector rise time, fall time and also the operating temperatures of the lasers. Both selected lasers show high operating temperatures, although it is preferable to keep the laser operating temperature at a stable point to avoid wavelength shift. Therefore the laser controlling circuit is designed with a timing component that makes the laser drive in for a very short time period, which is necessary to excite the monitoring area. A National semiconductor TLC555 timer is used as the center component of the timing circuit. The timer capacitance and the resistors are used in such a way that the current is driven in the circuit within one tenth of a second.

Fig. 3: Sum of the auto fluorescence and fluorescence of Photofrin in an epithelial cell12.
The timer output current is divided into separate two channels, using a decade counter as shown in the Fig.4. MC14017B five-stage Johnson decade counter is used in the circuit. This consumes very little power and gives a spike-free output. The decade counter can supply ten separate leads. In this application, only two leads are used while the rest are kept grounded. The circuit is set up to operate on each laser in a pulsed mode with every 0.9 second pulsed width and 0.05 second dwell to avoid thermal buildup inside the lasers. The lasers are connected to the emitter of an NPN transistor, whose base is connected to the main power supply, and the collector to the decade counter output. In this way, the laser power input is kept constant and at an expected value. The lasers are connected to the decade counter through transistors, where the main power source to lasers is connected. The silicon detector is connected to a 12V bias voltage supply. This is the supply voltage to the controlling circuit. The laser driving voltage of 2.3V is supplied from this source, through a voltage divider.

5. Fabrication of blood oxygen monitoring system

5.1 Probe design

For the prototype fabrication we have used packaged lasers and a germanium photodiode due to commercial availability and cost effectiveness. Un-packaged devices can be easily incorporated into the probe when the prototype design is verified with the experimental data. In the final design, the probe was encapsulated with a transparent polymer material to protect the complete circuitry from shear forces generated during insertion of the balloon catheter system into the esophagus. As shown in Fig. 5, the photodiode and lasers are packaged in a Teflon block.
wire connections for the detector and the lasers are at the bottom of the package, firmly connected to the block, where possible mishandling would not damage the wire connections.

5.2 Data acquisition and data acquisition system

LabVIEW (National Instruments) is used for data acquisition and the desired output. NI-DAQmx a subprogram in the LabVIEW is used in developing the virtual instrumentation for the oxygen detection system, which is now used in most of the industrial setting for data acquisition and instrument control.

The front panel of the LabVIEW consists of three different waveform charts that provide the raw detector signal without digital filtering, the digitally filtered input signal, and the variation of hemoglobin and oxyhemoglobin. NI 6221 DAQ card was used with SCB-68 shielded I/O connector block. The SCB-68 opens the connection to the controller circuit with virtual instrumentation. The detector voltage outputs that belong to the respective lasers are fed to the connector block. LabVIEW DAQ, signal conditioning hardware and software, provides graphical development of the control. DAQmx detector output signal is split into two signals as the initial step in the process. These signals are acquired with a certain time difference, which is removed by modifying the signal at second stage by adding the time difference to the trailing signal. Optical input to output ratio is calculated thereafter. The signal is then sent through a band pass filter before it is input to the mathscript node.

6. The experimental setup

The experimental setup consists of the proto board where the controlling circuit was built, two power supplies, two multimeters and a personal computer in which NI LabVIEW was installed. The detector reading acquired by the LabVIEW program is validated with the multimeters connected to the physical channel of the detector output. The circuit design is assumed to have zero generation of crosstalk, since the current and signals always travel in one path at any given time. Following this, the interference of signals in different paths is minimal and the noise generated is negligible.

The actual system does not consist of these additional equipments. Final instrumentation consists only of the DC power supply, in addition to the controlling circuit and the probe. The DC power supply is set for the 12V output, which is necessary for the detector reverse voltage. This system can be easily powered by a 12V battery pack, when there is no main power supply available. The preliminary testing with the probe and the detection system was done with the upper limb of the author. Even though the system is designed for the use in esophagus, it is not possible to conduct an in-vivo testing with the esophageal tissue under currently available laboratory conditions. The probe was moved to several places to observe uninterrupted reading, yet it was noted that the pulsative blood flow adds a degree of noise to the reading. This noise however, does not to the general reading required to monitor the oxygen level.
6. Preliminary results

A set of experimental results was obtained to validate the probe design and the data acquisition system, using the author’s upper arm. The probe was firmly held against the skin by a tape, as shown in Fig.6. The absorption and scattering of 904 nm light is comparatively less than that of 650 nm light. Therefore the ratio of the light signal emitted by the laser to the light signal received by the detector is higher in the higher wavelengths. The detector signal was slightly different when the probe was placed on the limb since the blood flow, in pulsatile manner, adds noise to the detector signal. This noise does not deteriorate the monitoring process since it was present throughout. Attenuation is possible by selecting a monitoring location such as the ear lobe, with minimal interruption by other blood vessels. However, the selection of such a placement is only necessary for calibration purpose, since the final probe design should be able to monitor the esophageal environment, which is closer to the heart.

The final set of reading was obtained to verify the system capability to capture a change in blood oxygen level. Application of a 140 mmHg pressure to upper limb, which is above the systolic blood pressure for a particular subject, will cut off the blood supply completely for the period of pressure application. As a consequence, the fraction of deoxyhemoglobin in the distal part of the upper limb is increased. The difference of oxyhemoglobin and deoxyhemoglobin is detected by the monitoring system, as shown by the separation of the two data lines (Fig.7). Figure 7 illustrate the oxyhemoglobin (—●—) reading and deoxyhemoglobin (—■—) reading for 120 second where application of pressure is initiated in 20 second after the beginning of the reading. Further verification of the system with Photofrin® contacting environment is required to test how far the system fulfills the design objective.
7. Discussion

A photonic reflectance oximeter is designed, analyzed, and fabricated. The specific device selection, to be used alone with PDT, is discussed. The application of the designed system is not specific to esophagus. The system is designed either to be used inside an internal organ or on the skin, where melanin plays a major role in light scattering and absorption. The virtual instrumentation is developed to change its formulation in accordance with the location of the monitoring. The virtual instrumentation instantly gives the change in blood oxygen content and the blood volume. The absolute change in oxygen level can be derived by calibrating the system, using existing oxygen monitoring systems. The change of oxyhemoglobin and deoxyhemoglobin is given relative to the initial level of each component. This is an important advancement in the case of PDT.

The prototype used commercially available lasers and detectors so that the current probe is relatively large in size to be compared to the light delivery system to be designed for the esophagus. However, it is not a complicated task to fabricate a probe that can be imprinted onto a balloon catheter. The oxygen detection system can be further modified and incorporated into the light detection system, added to the rear side of the detector probe, for monitoring of the photosensitizer fluorescence signal. All commercially available photosensitizers give a significant fluorescence signal that can be easily filtered and used for monitoring purposes.

References


BIOGRAPHIES

Dr. Gemunu S. Happawana is an associate professor in the department of mechanical engineering at California State University, Fresno. Dr. Happawana holds a Ph.D. (1994) in mechanical engineering and Master of Science degree (1988) in mathematics from Purdue University, and Bachelor of Science degree (1984) with honors in mathematics from University of Colombo, Sri-Lanka. His work lies in the fields of mechanical vibration, applied mechanics and photonics, and it combines physical modeling, analytical techniques, and measurement. Dr. Happawana serves as advisor to Mini-Baja and Formula SAE student competitions. Dr. Happawana is a consultant to the high tech photonics company, Photodigm, Inc., Dallas, Texas, since 2000. He is named as Patton Industry Faculty Fellow. He has worked on converting gasoline engines to run on ethanol, natural gas or kerosene. He has more than fifty journal and conference papers, one book and two patents pending. He has graduated four Ph.D. students and served on over twenty Ph.D. and MS committees. Affiliations: SAE (member), ASME (member), OSA (member).

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SimzLab - Interactive simulations of physical systems for active individual and team learning

by

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Teaching by lecture and textbook alone does not satisfy students' needs. Many physical systems are too complex to be conveyed fully by the static plots and drawings in books. Essential to learning is active practice and application of new knowledge. Real experiments are wonderful - but cost and space constraints limit the number which can be implemented - usually from zero to a few in most courses. Interactive software simulations can engage students actively in the learning process and help them to understand and work with complex systems. Interactive simulations engage the student²,³. They are interesting and fun to use⁴-⁶, and help students take responsibility for their education⁷.

This paper describes a software application – SimzLab⁸ - and what we have learned from developing and using it. Our main objective has been to provide students with virtual lab modules to supplement lecture courses on chemical processes.

SimzLab can distribute multiple sets of modules or "Labs" over the Internet, with each Lab hosted on its own server. The current Labs are Reactor Lab (simulations of chemical reactors) and PureWaterLab (modules on water purification and use). Programming has been done at UCSD and the explanatory text in PureWaterLab has been written at the University of Arizona.

SimzLab is a desktop application which communicates over the Internet with servers. Since it is a desktop application rather than a web browser, it has the full capability of an application such as running compiled C executables for compute-intensive simulations. Since it can connect to the Internet, it has access to protocols such as HTTP, FTP, and TCP/IP sockets.

The software has been developed using a tool with a graphical layout editor and a high-level scripting language¹. On each client, there is one executable file which has been compiled for that platform (hardware and operating system) and which contains minimal bootstrap code or "script." All other scripts are contained in files which are cross-platform. Whenever a student goes on-line, SimzLab updates any file - both script and content - on the client for which there is a newer version on the server. Currently we only provide Mac and Windows versions of SimzLab, although Linux versions are possible.
Students download the SimzLab application from the web site at www.SimzLab.com at no cost. A few modules are provided in the initial distribution. When a student connects SimzLab to the Internet, the student can download additional modules. Once downloaded, a module can be used off-line.

Fig. 1 shows the opening window and the two courses available.

![Opening window showing the sets of course modules currently available.](image)

In the Reactor Lab, many of the modules have two sections: the main entry point in which all inputs and outputs are known to the student, and a quiz section. In the quiz section, students must run experiments, analyze their data, and then check to see if they have an answer within an acceptable range. The Lab charges virtual $ for each experiment to teach students that they should not run experiments indiscriminately, and then awards them virtual $ for correct answers. The Budget Report records the history of each quiz. Students must turn in their data, analysis work, and a copy of the Budget Report which contains an authentication code. These quizzes incorporate the features Pavia lists that should be exhibited by a laboratory simulation.

It is interesting to observe a new group of students start to use the software in a computer lab. Doing homework in the Lab is much different that working the usual end-of-chapter homework problems, where usually the necessary and sufficient set of data are given such that a unique answer can be obtained. Some students get the idea and use the Lab enthusiastically. Some students stare at the computer with a concerned look, unsure where to begin. They aren't given data; they have to perform experiments and take their own data and their first experiments may be under conditions which do not provide useful data.
One student was angry, protesting "We are only undergrads! We only know how to work textbook problems!" To which we thought, "Yes, that's exactly the problem!"

As far as functionality, we observed that students highly value software responsiveness (speed) and the ability to use software without having to read instructions.

The Reactor Lab has been used by students all over the world and has been translated by volunteer students and professors into Spanish and Portuguese. Although gratifying, we felt that greater use of the Lab could be obtained if more complete modules with explanatory text were provided in addition to lab simulations. And so, in PureWaterLab, we are developing both explanatory text with graphics and interactive simulations.

The current PureWaterLab course includes an overview on how ultrapure water (UPW) is produced, and detailed modules on specific process components including reverse osmosis, UV photo oxidation, and ion exchange. Fig. 2 shows the Directory window of PureWaterLab.

A fourth module in the Process Units division, activated carbon treatment, is under development. The modules include background information, design parameters, treatment capabilities and uses as well as interactive quizzes and homework problems. The simulations are designed to maximize flexibility from “black box” canned response with little user input except for inlet conditions to detailed inputs and operating conditions for more advanced users. Fig. 3 shows a typical the text explanation window and the basic level simulation window open. The module presented in Fig. 3 describes reverse osmosis.
A more advanced simulation for reverse osmosis is presented in Fig. 4.
At the start of preparing the text and graphics, we discovered that the team members at the University of Arizona wanted more control over formatting than could be provided by the development tool. Therefore, we switched to letting the authors create web pages. The web pages are rendered by the default browser on the client (Internet Explorer on Windows and Safari on Mac) in windows that are "skinned" by PureWaterLab. Any web component that can be rendered by Internet Explorer or Safari can be displayed by SimzLab.

This raises the question, "Why not distribute the complete modules as web pages accessed with a standard web browser?" The reason is that we wouldn't be able to deliver simulations with the full range of functionality that we require. In addition, SimzLab can add additional functionality not present in standard browsers. An example is that it scans pages for words in the Glossary, adds HTML tags next to the first occurrence of each word found, and displays definitions in an information field below the web page as the user mouses over the now highlighted vocabulary words.

One feature we would like to develop further is the "Conference Room." This is somewhat of a cross between a bulletin board and a chat room. It gets most active the night before a homework assignment is due at UCSD, when students ask each other for help. On one occasion, we had a three-way conversation between a professor in San Diego, a postdoctoral associate from Turkey in Ann Arbor, and an undergraduate student in Turkey.

A recent addition to PureWaterLab is a module for constructing and conducting dynamic simulations of water purification plants. The connection to the Internet allows students at different universities to collaborate on running the same plant, with one team of students operating one part of a plant and teams at other universities operating other parts of the plant.

Students can construct a process plant by adding process units and pipes to a flowsheet, as shown in Fig. 5. Material flows between units are represented in the software by messages. In Fig. 5, the blue unit on the flowsheet is the local proxy of the actual unit, which is located on a remote computer. Messages between computers are written in XML text and sent over Internet between the computers via TCP/IP sockets. Since messages between computers are in platform-independent XML text, the simulators on individual computers can be written in any computer language running on any hardware. Since the “internals” of units do not have to be known or “exposed” to users, future uses may include units posted by companies to allow students and prospective customers to experiment including a commercial unit in their process. The potential advantages of distributed dynamic simulators have been discussed by Shemeikka, et al\textsuperscript{10}. 

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A CONCEPTUAL APPROACH TO DEVELOPING A UNIVERSAL REMOTE LABORATORY FOR EDUCATION AND RESEARCH IN ELECTRICAL POWER ENGINEERING

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Abstract

One crucial element of education in electrical power engineering is the laboratory component. The laboratory instruction may be delivered in physical laboratories using real equipment or through simulation software tools, and in many cases utilizing both simulation and real equipment. Remote laboratories, where experiments are performed on real equipment remotely via simulation interfaces, have recently gained keen attraction. In this paper, a novel approach to delivering remote laboratory education is presented. The major components forming the new laboratory system include a real power system, an online monitoring and control station and a web client-server system. Sample activities that may be performed remotely through this laboratory are described. These activities range from a simple experiment for evaluation of transformer performance to more involved studies such as voltage stability and generator startup. Renewable energy activities may also be added. In addition to laboratory instruction and applied research, this remote laboratory is expected to be an ideal setting for distance learning.

Introduction

Laboratory instruction is a critical part of a solid Electrical Power Engineering curriculum. It is well presumed that hands-on experimentation is a vital practice necessary for all graduating electrical engineers. Traditionally, the laboratory requirement in power area for most Electrical Engineering curricula involves a course in energy conversion principles covering dc and ac machines, transformers and introductory power electronics. In recent years, the use of computer simulation tools for laboratory education has been noticeably widened. However, studies normally performed on utility power systems have always been simulation-based. These include power flow analysis, short-circuit studies and power system stability among other studies. With rapid developments in computer visualization tools, virtual depiction of most engineering concepts and design methods is now possible and fairly affordable. Advances in communications and in digital signal processing and the wide use of the Internet have led to the feasibility of remote laboratories. In this case, real equipment and instrumentation may be housed in a remote location while the control of this equipment can be performed locally. Furthermore, the instrumentation and equipment can be animated locally in conjunction with real audio and video received form the remote equipment location. This virtual local animation of a laboratory is the front-end of a real laboratory which is located remotely.
Laboratory Types

Laboratory education may be delivered via three types of laboratory settings; real, simulation and remote, each with distinctive merits. In a real lab, there is a face-to-face experimentation with real equipment. The simulation lab, however, allows working only with simulated models of the devices. Working remotely with real devices through virtual depiction of these devices via software user interfaces is termed as remote lab.

A comparison among these types has been presented. The debate continues over the effectiveness of each laboratory type; real, virtual or remote on meeting the objectives of laboratory education. Based on a local energy plant, an energy system laboratory was developed such that real-time data could be collected for simulation studies. A previous work presents a comparison between face-to-face students carrying out experiments in a real laboratory and distance students performing the same experiments in a virtual lab. It was shown that distance students were not disadvantaged compared with students working face-to-face. An internet-based approach was followed for remotely using real equipment located in multiple universities. The role of laboratory component in power engineering education was discussed by an IEEE panel. Further literature review indicates the tendency and favorability toward virtual laboratory mode particularly when the virtual laboratory site is linked to a remote real laboratory.

Laboratory Description

The envisioned remote power laboratory is a small power system independent of the power grid and is composed of a set of generating buses (mostly renewable energy sources such as solar PV panels and wind power units), and a transmission system including transformers, overhead lines and underground cables. Fig. 1 shows a schematic diagram of the proposed laboratory system. Various types of loads such as induction motors with variable frequency drives can be connected at different buses. A fully coordinated protection scheme may be installed. As an essential part of this laboratory, a real-time monitoring and control system must be developed with the capability of controlling all protection and switching devices. Users of this remote lab will simply be web clients with a variable-permission protocol for monitoring and/or control of different parts of the system. Continuously updated experiments can be designed, tested and made available for use by clients.

Sample Laboratory Activities

The following activities may be performed remotely via virtual user interfaces:

1. Transformer Performance
   a. Record one set of instantaneous values for the input and output voltages and current in addition to their phase relationships.
   b. Knowing predetermined values of the transformer equivalent circuit evaluate and verify the values of the input voltage and current in terms of the recorded output voltage and current.
c. Evaluate the input power, output power, losses and transformer efficiency under the given loading conditions.

d. Calculate the percentage voltage regulation under the same loading conditions.

Fig. 1. Schematic view of the proposed remote laboratory system

2. Motor Acceleration and Variable-Frequency Control

a. Start an induction motor under known loading conditions and record the motor parameters from start to full-speed following a certain starting method.

b. Repeat step “a” using additional starting methods.

c. Study the performance of the motor during starting under these different methods.

d. Vary the motor speed using a variable-frequency drive and record motor current waveforms.

e. Analyze the harmonic contents of the motor current.
3. Power Flow Analyses
   
   a. Record the voltage magnitude at each bus at a given time.
   b. Using the values found in step “a” as initial values, perform the load flow study.
   c. Compare the simulated output results with the real-time data shown on the virtual interface.
   d. Study the significance of line losses and voltage drops on various branches under different loading conditions.

4. Short-Circuit Analyses
   
   a. Perform a pre-tested short-circuit scenario and observe the operation of various protection devices.
   b. For the conditions of “a”, perform a simulated short-circuit study.
   c. Repeat steps “a” and “b” for other pre-tested short-circuit studies.
   d. Compare the simulated output results with the real-time data recorded.

5. Device Coordination Study
   
   Using a radial primary distribution feeder, coordination of various protection devices may be presented. Real time performance of the relays both as primary operations and as backup operations may be tested.

6. Voltage Stability
   
   Voltage instability occurs due to primarily the lack of sufficient reactive power support. Susceptibility of any bus to voltage collapse can be studied by evaluating the sensitivities of the voltage at these buses to changes in the injected reactive power. Other dynamic factors may be investigated as well.

   a. Select a load bus to undergo a voltage stability test.
   b. Monitor and record bus voltages in addition to active and reactive power flow
   c. Vary incrementally the load at this bus until the voltage collapse occurs.
   d. Evaluate the voltage stability sensitivity indices.
   e. Study other factors that may influence voltage stability.

7. Emergency Generator Start-up
   
   Another importance experiment for power engineering students is bringing up a backup generator online. Whether triggered by a loss of power signal or a manual startup case, there are certain conditions need to be met before actual connection occurs. This experiment may be designed such that the conditions for a successful startup be monitored and analyzed, then, a command for execution is sent. One condition to verify is that the loading condition (both real and reactive power) during startup allows a valid generator operating point.
Renewable Energy Activities

Other activities may also be added to include renewable energy links. For example, a photovoltaic panel system can be a part of an experiment covering the maximum power point tracking process. An experiment aiming at power conditioning from a wind generator as well as its overall performance is another example.

Concluding Remarks

A universal remote laboratory has been suggested for education and research in the area of electrical power engineering. The conceptual laboratory offers unlimited expandability to cover a wide range of topics and educational experiments. Working with a real system in addition to advanced visual animation technologies, users are expected to gain immense doses of practical experience. A cost analysis for a start-up practical system is yet to be performed.

References


Teaming Multi-level Classes on Industry Projects  
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Abstract

For the past few years we experimented with teaming students from a sophomore-level class and a senior-level class to work on industry projects. The classes are “work design” and “facilities design.” Projects are selected to require the application of knowledge from both disciplines. In addition, the projects are selected from small local companies. The intent of this paper is to describe the benefits and difficulties associated with this methodology. While specific classes in this experience are typical of an industrial engineering curriculum, the lessons learned and benefits could translate to other disciplines.

Introduction

The use of Project Based Learning (PBL) has contributed to Cal Poly’s reputation of “learn by doing” for many years. As part of the Industrial Engineering (IE) curriculum at Cal Poly, students work in small groups with local companies on facilities related projects. The unique aspect of these projects is that students from a senior class and students from a sophomore class are partnered together to work on these industry based projects. These projects have been received favorably by the students, the local companies, ABET evaluators, and our industrial advisory board. As in many PBL activities, we observed that students develop better teamwork skills and better solutions to design problems. In addition, there are unique outcomes for the younger students including a higher commitment to their chosen major, and a better context for future classes. For the older students working with the younger students, the outcomes include review of lower level topics and enhanced supervisory skills.

This paper begins by reviewing the literature in the area of PBL and teams, describes the project and processes involved in these project teams, and delineates lessons learned from both the instructor’s and the student’s points of view. Areas of future research will also be discussed.

Review of Literature

Most engineering schools use team based projects, or laboratory assignments to help students develop skills necessary for their professional careers. Teamwork skills have traditionally been developed by assigning students to teams. To some extent, this approach does produce results, but a better approach was undertaken at the University of Dayton[4] where student teams were instructed on teambuilding and leadership. One of their suggestions was not only to instruct, but to give students opportunities to work on teams where students refine their skills as they mature though the engineering program. Many researchers have struggled with the difficult task of assessing teamwork and other soft skills involved in multi-disciplinary PBL teams. Plumb and Sobeck[10] put together a framework for developing assessment tools. They urge instructors to develop a rubric or protocols to track performance over time.
Teamwork in PBL is a unique case in that the teams are usually working on more difficult, time consuming problems. When PBL is used students achieve desirable outcomes. Several researchers at the University of Madrid\cite{7}, 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\cite{6}. 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 sited as an important component of learning in PBL. In the Civil and Chemical Engineering school at RMIT, researchers\cite{5} examined the factors that effect engagement in a PBL environment. They examined first year engineering students and identified four 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. Lastly, students require guidance and orientation to their new university environment.

Several studies have looked at team structures that include individuals from varying educational levels. Some have included graduate students on teams with undergrads, while others have grouped high school students with university seniors. At Boise State University\cite{9}, faculty, post-doc, graduate students, undergraduate engineering, and undergraduate technology students are put on teams together in laboratory courses. Although only in the beginning stages of this curricular change, these researchers feel it will be an effective method to simulate the working environment for the future graduates. Adams, Zhang and Burbank\cite{1} placed undergraduates and graduate students together on teams with the explicit goal of preparing undergrads for graduate study and research. They observed both increasing graduate enrollment and higher quality of graduate students after implementation of these teams. The School of Electrical and Information Engineering at the University of South Australia experimented with grouping seniors with high school students on a design project\cite{8}. The projects were university sponsored, but industry generated. The high school students reported better learning of technical skills and the older students developed management and communication skills. In addition, the younger students felt they could make more informed career choices.

Related to teaming in PBL, the use of teaching assistants (TA) as substitutes for faculty in guiding PBL experiences was explored at Deft University of Technology in the Netherlands\cite{2}. There were clear advantages delineated, which included the ability of TA’s to establish good social and peer relationships with student teams. In addition, TA’s were unable to give direct step-by-step guidance, which proved to be an advantage to learning for the student teams. The researchers stress the importance of thorough recruiting and training of the TA as an important success factor. Also, Crosby, Ibekwe, Li, Pang and Lian\cite{3} developed a tiered mentoring approach as part of a larger research project. The faculty mentor the graduate students who in turn mentor undergraduates. In turn, the undergraduates mentor high school students. These researchers state that they feel confident this type of activity will increase recruitment and retention.
PBL and teaming have clear advantages to students, and it seems that even grouping students at different experience levels can achieve excellent outcomes. This research takes these experiences one step further to look at a sustainable system to enhance learning outcomes.

The Courses and Projects

The two courses described below are only two of many courses in the IE curriculum that use PBL. These courses are the first in which we grouped senior students from one class with sophomore students from another to work on industry generated projects.

For more than ten years the senior facility design class has conducted projects for local companies. 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, but also companies in Stockton and the LA area have participated. 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 1 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 1 - Sample Projects

<table>
<thead>
<tr>
<th>Company</th>
<th>Location - CA</th>
<th>Company Type</th>
<th>Project Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C&amp;D Aerospace</td>
<td>Santa Maria</td>
<td>Aerospace</td>
<td>Redesign of an assembly cell</td>
</tr>
<tr>
<td>Hardy Diagnostics</td>
<td>Santa Maria</td>
<td>Biomedical</td>
<td>Design layout for a new location</td>
</tr>
<tr>
<td>Dioptics</td>
<td>San Luis Obispo</td>
<td>Distribution</td>
<td>Design new warehouse</td>
</tr>
<tr>
<td>Road Home</td>
<td>Oceano</td>
<td>Non-Profit</td>
<td>Design a homeless shelter/campus</td>
</tr>
<tr>
<td>Left Coast T-Shirt</td>
<td>San Luis Obispo</td>
<td>Screen</td>
<td>Re-layout production floor to incorporate new machine</td>
</tr>
<tr>
<td>SLO Roasted Coffee</td>
<td>San Luis Obispo</td>
<td>Food</td>
<td>Design new layout to incorporate new packaging process</td>
</tr>
<tr>
<td>UVS Thrift Store</td>
<td>San Luis Obispo</td>
<td>Non-profit</td>
<td>Re-layout and methods improvement</td>
</tr>
<tr>
<td>Moulton Logistics Mgmt</td>
<td>Van Nuys</td>
<td>Distribution</td>
<td>Redesign of reverse logistics area</td>
</tr>
<tr>
<td>New Life Church</td>
<td>Arroyo Grande</td>
<td>Non-Profit</td>
<td>Design of new youth center</td>
</tr>
<tr>
<td>Jamba Juice</td>
<td>San Luis Obispo</td>
<td>Retail</td>
<td>Redesign of retail location</td>
</tr>
<tr>
<td>Diamond Foods</td>
<td>Stockton</td>
<td>Food</td>
<td>Redesign assembly line production area</td>
</tr>
<tr>
<td>Wasco</td>
<td>Santa Maria</td>
<td>Electronics</td>
<td>Design of a new facility</td>
</tr>
<tr>
<td>Corbett Canyon Winery</td>
<td>San Luis Obispo</td>
<td>Winery</td>
<td>Re-layout of a bottling line</td>
</tr>
<tr>
<td>Fountains of Living Waters</td>
<td>Santa Maria</td>
<td>Wholesale</td>
<td>Layout of a new facility</td>
</tr>
</tbody>
</table>

Students also learn first hand, 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.
The second course, Work Design, is one of the first major course IE students take. In this class students learn basic methods of time studies, continuous improvement procedure, and lean manufacturing concepts. They are also introduced to ergonomics and work station design. For many years students in this class have been applying these concepts to real life situations. Often students find a project themselves, and occasionally the instructors provide a project. Whatever the project, students are encouraged to recommend a justified improvement to an existing procedure using time studies and other quantitative measures.

Because these two courses have a history of working on real life projects for companies, a couple years ago we experimented with combining the projects and students so that several students from each class work on the same project. Generally the teams are made up of four upper level students and two lower level students. The tasks are loosely divided between facilities design and work study, but these are naturally integrated requiring students to interface for project completion.

Currently, not all students participate in these multi-level teams. Generally there are seven or eight facilities teams, of which four have students from the lower level class. In addition, there are seven or eight teams in the work design course, of which four are students participating on teams with the seniors.

As an example, a student team made up of five seniors and two sophomores worked for a local winery developing the layout of a new bottling line. Initially, the students visited the winery for a tour. This was followed by the upper level 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. Work design students created process charts, and collected time study data on the processes. The facilities design students used this data to create a simulation using Promodel® (a discrete event simulation software that includes graphics) that illustrated bottlenecks and justified task automation. All the students in the group worked on research of automation equipment and developing alternative layouts for the line. The facilities student performed economic evaluation and evaluated quality issues. Work design students created lean manufacturing work stations equipped with 5S shadow-boards[11]. All students worked on recommendation for ergonomic improvement. A comprehensive report, approximately 100 pages long, a professional presentation, and a physical model of the recommended line was delivered to the client after six weeks of intense project work. The quality of the report was high and the client was pleased with the many creative cost-benefit justified ideas.

Learning Outcomes

The fact that these courses use PBL to teach some valuable topics should not be overlooked, but in addition, the students are learning topics that are unique to this multi-level teaming experiment. Below these outcomes are delineated into those achieved by everyone participating in the multi-level teaming, those achieved by the senior students, and those achieved by the sophomore students. The description of each outcome is followed by a quote from a student in the classes. These quotes were collected as part of an anonymous survey of the participating students. Summary data from this initial survey is also included where appropriate.
Outcomes for all students. Students in both classes are heavily engaged in the projects and thus are acquiring skills at a high level. They are also learning enhanced teamwork skills by dealing with individuals different than themselves.

- Working with students in 443 (facilities design) gives the 223 (work design) students an idea of what sort of workload to expect and the complexity and various challenges of solving a specific problem within a team of people with various backgrounds and experience levels. (Sophomore Student)
- It was a lot of work, but I would definitely do it again. (Sophomore Student)
- I really thought that the class was a lot of fun and a great learning experience. (Sophomore Student)
- I really enjoyed working with the upper classmen. (Sophomore Student)

When the younger students were asked “Did you learn more from this project than other projects you worked on?” 71% answered, “I think I learned a lot more working with the seniors.” In addition, 68% of the students reported that they worked “very hard” on the project.

Outcome for senior students. Seniors learned supervisor skills and had a chance to refresh their memory of topics learned as sophomores.

- I did learn how to supervise and delegate jobs through an understanding that they were lower classmen. (Senior Student)
- It was tough to get them to find their own work to do (basically we didn’t want to hold their hands). Definitely learned a lot about delegation. (Senior Student)
- It was nice to have upper classmen in my group as they were able to guide us through the hard aspects of the projects. (Sophomore Student)
- I liked working with them because they refreshed my memory on how to do time studies. (Senior Student)

Outcomes for sophomore student. Sophomore students expressed increase knowledge of the curriculum, development of mentoring relationships, and an increased dedication to their chosen major.

- The seniors as well as the project defined my interest and choice of IE as my major (Sophomore Student)
- It helped give an understanding of what would be coming in the future. (Sophomore Student)
- I loved hanging out and working with upper classman; it helped me set some goals of what I want to be doing in the next couple years while I'm at Cal Poly. I thoroughly enjoyed it. :) (Sophomore Student)
- I didn't just learn about work study in class, I also gained knowledge from the project and the upper classman. (Sophomore Student)
- I remember during the project, I became good friends with the seniors in the group (Steve and Edgar) and they both basically became mentors to me. (Sophomore Student)
After this project, I was sold on Industrial Engineering as the major for me. (Sophomore Student)

It was great to get a preview of what we would be learning later on. (Sophomore Student)

The upper classman and working with the company showed me how complicated and how many different perspectives IE's have to pay attention to when doing a job for a company. (Sophomore Student)

Working with seniors put extra pressure on me to want to perform better for my peers. (Sophomore Student)

When asked “Did the project change your opinion of IE as a career?” 89% answered “It made me more interested in my major.” When asked “Did you feel appreciated?” 78% answered “Yes, they appreciated me.”

Lessons Learned

By combining students from different class levels several important objectives were realized, but there are also some important lessons we learned. These include techniques that proved helpful and areas of caution.

Project definition. We, as the instructors of these classes, recruit companies to participate with appropriate projects before the term begins. These projects must be of the appropriate scope, size as well as include some level of ambiguity. Projects must include IE tasks such as time studies, ergonomic evaluation, and facilities implications. Careful selection of projects proved to be critical for student success. Some facilities projects do not have tasks for work design students, these projects are still being worked on, but no sophomore students are assigned to these teams.

Company participation. Companies that participate in these projects are asked to have one contact person who can communicate with students. In addition, they must attend two presentations: an interim presentation and a final presentation. It is very important that companies are told in advance of these expectations. In some projects, the companies are shocked at the sheer number of questions students can generate. We, as instructors, try to encourage students to think hard before they ask too much, but sometimes communications can get burdensome for the companies. In these few cases, the companies must be able to deal with the instructor directly so that adjustments can be made.

Course structure. These projects work best if the two courses have lab activities that are scheduled concurrently. The groups must meet together and the difficulty of scheduling these meetings is minimized if students are guaranteed to be available at the same day and time. The two courses are separate and are run by different instructors. Each class has topics that must be addressed and lab activities that must be performed. The difficulty in scheduling should not be minimized.

Timing of instruction. One of the difficulties encountered when using any projects in a course is that it is not easy to cover all the topics in time for application to the project. This is especially true in a quarter system. In the senior design class this is solved by intense lecturing during the
first five weeks of class and project work during the last five week. This structure is not possible in the work design class, yet some important topics are needed at the beginning of the quarter. In order to solve this, we cover time studies very early, and this may sacrifice a logical sequence of topics.

**Teamwork instruction.** It is very important to introduce this multi-level teaming to the classes in a way that they understand the reasons behind the procedure. The seniors need to understand that the sophomore students are full team members. The younger students will be assigned specific tasks, but should be respected for their contribution and even encouraged to stretch themselves by creative problem solving. The seniors are also asked to consider themselves teachers and mentors of the younger students. In one group, the younger students were not treated as equals and the faculty members did not intervene in time to remedy the problem. The younger students were demoralized and hated being part of the team. In addition, the seniors on this particular team had major conflicts and the poor quality of their final presentation reflected their dysfunction. The younger students need to understand the time commitment and complexity of the project. It is possible that not all sophomore students can handle the intensity of these projects.

**Assignment of individuals to teams.** We have found that it is important for the faculty involved to assign teams and not to allow students to choose their own teams. For the seniors on the teams, there must be students with a mix of skills and experiences. For the sophomores, the students should be informed of the complexity of the task and have the option of working with the seniors on these more complex projects. In the sophomore class students are asked to volunteer for the facilities projects, and typically there are a greater number of sophomores wanting to do the complex projects than there are spots on the project teams.

**Use of electronic communications.** Because the students are in separate classes, communications is sometimes a challenge. The use of communication devices such as Blackboard or Google Groups has enhanced document transfer and simplified interactions.

**Good teamwork techniques.** The students on the teams are encouraged to practice good teamwork techniques. Students are required to create an agenda for each meeting and keep track of activities using project management. In addition, teams are encouraged to have team-bonding activities that increase the cohesiveness of the teams. Students also must deal directly with team conflicts. We, as instructors, have had to gather students together to openly discuss conflicts. This is quite difficult, and not all instructors are comfortable in the role of mediator.

**Communication between instructors.** The communications between the instructors should ideally be frequent and easy. In our classes, the instructor for the facilities class organizes the companies and the schedules, but discussion about team membership and dealing with problems along the way is the responsibility of both instructors.

**The number of projects.** These projects are managed as part of the regular teaching load of the faculty. There are approximately 250 students in the IE major at Cal Poly, this means that each quarter there will be as many as ten student groups working with companies. This requires
considerable coordination with the companies and motivation of the teams. This multi-level teaming may be easier to sustain if additional resources are allocated.

Procrastination. Students tend to procrastinate. Because of the nature of these complex problems, procrastination can really hurt the final product. In addition, because the projects are ambiguous by design, students have a hard time at the beginning of the project moving ahead with a solution methodology. Due to the nature of the project, if the upper classmen are procrastinating the lower classmen will be adversely affected. The way we have dealt with this problem is to push students hard to show early analysis and data collection, but we still struggle to get some students teams moving early enough.

Exposure of sophomores to seniors. Sometimes the students in the work design class are freshman; as young as 18-years old. Seniors must remember this when dealing with the younger students, they must be careful about mature activities such as drinking and partying. We, specifically warn senior students to be mindful of the age of their teammates.

Conclusions and Future Research

We found that teaming lower level IE students with upper classman led to several desirable outcomes. For the younger students they gained a greater appreciation for their choice of major, they develop mentoring relationships, and they develop knowledge of technical aspects of IE. Upper classman also acquired important skills, particularly management skills and relearning of topics. Both age groups of students expressed satisfaction in the experience. Although the activities described in this paper are done with IE students, other disciplines can realize similar benefits by teaming lower and upper level students together on project teams.

We have been able to sustain these project teams for several years. It is the hope that as we refine the procedures and prove the benefits, these multi-level teams will become an official part of the IE curriculum.

Although we have seen much success in their multi-level teaming, there are still more opportunities to refine the procedures. We are currently in the middle of a quarter where students have been asked to fill out surveys on abilities in teamwork, supervision and other observed outcomes of the multi-level teaming. We administered the survey to all students in the two classes, approximately half of them are participating the multi-level teaming while the other half are working on teams with their classmates. We are hoping to find differences in the groups dependent on the team type.

In addition to students from these two classes, it seems feasible to have students from other courses working with companies on multi-faceted teams. Currently, courses in simulation, design of experiments (DOE), human factors, and project management are working on team projects. It is conceivable that these classes could be partnered together to work on complex problems for companies with good results.
List of References


Biographical Information

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Computer Applications in Mechanical Engineering

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Introduction and Motivation

Juniors in mechanical engineering at California State University, Sacramento (Sacramento State) are required to take a 3-unit course titled “Computer Applications in Mechanical Engineering (ME 175)”. Prior to the fall 2000 semester, FORTRAN and MATLAB were the primary software packages used. The prerequisites are (i) any high-level programming language including C and C++, (ii) engineering materials, (iii) circuits and (iv) engineering mechanics – statics. The mode of course delivery is two 50-minute lectures and a 3-hour laboratory per week. Emphasis was on the introduction to numerical computation and assigned problems were solved on a PC/Workstation. Tests and final exams that rely heavily on computation were used to evaluate student performance; laboratory reports were used to assess writing skills. It was observed that a typical class was made up of two types of students; those who enjoyed programming, and students who considered programming as drudgery and were not motivated to do more than the minimum amount of work required to get a passing grade. The latter group also had difficulty relating the computer exercises in the textbook to real-world applications. After teaching this course a few times, the author decided to explore methods that might make the course more exciting to a greater number of students while remaining challenging. After some research it was decided that computer control of objects using microprocessors might be a good addition that will allow the students to test their programming skills, complement the techniques encountered in the numerical exercises, and at the same time lead to fun and challenging designs.

Objectives

The objectives for ME175 are to:

- Provide students with a basic exposure to numerical methods.
- Use MATLAB as the software environment to conduct numerical analysis.
- Perform simulations using SIMULINK (a MATLAB toolbox).
- Reinforce principles of computer science, electrical engineering, mechanical engineering through open-ended robot design with the Basic Stamp (a microcontroller).
- Engage students in problem solving via team work.
- Provide a brief introduction to the design process.
- Give students an opportunity to demonstrate oral and written communication skills through oral presentations and final project demonstrations.
Serve as a useful prerequisite for courses such as controls, mechatronics, modeling of dynamic systems, vibrations, and capstone design.

Course Structure

Beginning in fall 2000 the 16-week semester course was restructured such that 8 weeks are devoted to the theory of numerical analysis and problem solving in the MATLAB environment. The numerical techniques covered in this course spanned topics encountered in a typical numerical methods textbook\(^{(1-3)}\). The topics covered are: introduction to linear algebra, the solution of systems of linear equations, curve-fitting, interpolation, and the solution of ordinary differential equations. In the next 2 weeks a brief introduction to controls and/or vibrations is given. The accompanying laboratory exercises involve simulations via SIMULINK, and provide some insight to model-based design for dynamic systems. In the last 5 weeks programming in the Parallax PBasic language, an interpreter for the Basic Stamp microcontroller\(^{(4-5)}\) is introduced. An open-ended robot design project is also assigned. The students present their projects in week 16.

The course syllabus shown in table 1 provides more details regarding course structure. Four 50-minute tests are administered on the MATLAB and SIMULINK portions; two of these tests cover the theory and the remaining two test the students’ programming skills. An oral presentation is required by each group in the preliminary phase of the robot design. The final examination consists of a powerpoint presentation, a demonstration of each group’s project, and a technical report. Every student in a group must write a portion of the report so that his/her writing skills may be assessed. Students evaluate their peers’ presentations and demonstrations. Grade distribution (MATLAB and SIMULINK 60%; project 40%).

Table 1. Course Syllabus

| Lecture 1: Introduction to Computing Environment (SacCT, UNIX, Voyager, Windows); Review of Linear Algebra http://www.purplemath.com/modules/index.htm |
| Lab 1: Introduction to software (MATLAB) Driver, Plots, Conditional Statements; User-defined functions; Exercises with vectors and matrices |
| Lecture 2: Global variables; Data files: Read and Write |
| Lecture 3: Graphical User Interface (GUI) (Instructor notes) Lab 2: Creating a GUI - Exercises with vectors and matrices |
| Lecture 4: Introduction to the PBasic Platform |
| Lecture 5: Review: Generating Plots in a GUI; Reading Data files Lab 3: Completion of GUI Exercises with vectors and matrices; Introduction to the Basic Stamp Microcontroller |
| Lecture 6: Programming in PBasic; Subroutines (i.e. User-defined functions) Lecture 7: Unavoidable Errors in Computing; Solving Systems of Equations |
| Lab 4: Microcontroller Basics with the Basic Stamp |

Proceedings of the 2009 American Society for Engineering Education Pacific Southwest Regional Conference
A Review of Structured Programming via GUI Creation

The title *Computer Applications in Mechanical Engineering* encompasses a wide area and gives the instructor flexibility to choose from a variety of mechanical engineering applications. Since students at the junior level who take this course have already received exposure to various high-level programming languages such as C, C++, FORTRAN, JAVA and MATLAB, the first few lectures constitute a review of and/or introduction to MATLAB programming. Emphasis is placed on user-defined functions and the creation of a Graphical User Interface (GUI). Also Matlab requires that users have a good understanding of matrix.

![Figure 1. A Graphical User Interface generated in MATLAB](image-url)

**Table 1. Course Syllabus continued**

| Lecture 9: Least-squares Fitting of Curve to Data |
| Lab 6: Curve Fitting |
| Lecture 10: Additional examples in curve-fitting; Extracting equations using best-fit |
| Lecture 11: Interpolation |
| Lab 7: Fit curve and obtain equation for best-fit |
| Lecture 12: Numerical Integration of Ordinary Differential Equations; Runge-Kutta Methods |
| Lecture 13: Analyzing non-stiff systems ODE45 |
| Lab 8: Solving Initial Value Problems using ODE45 |
| Lecture 14: Introduction to SIMULINK for solving Ordinary Differential Equations |
| Lecture 15: Application to Vibrations: Mass-Spring-Damper System using SIMULINK |
| Lab 9: Solving IVPs using SIMULINK |
| Lecture 16: Analyzing other systems using SIMULINK |
| Lab 10: Programming a microprocessor; constructing digital circuits |
| The Final Project (Lectures and self-paced labs) |
| Technical Writing |
| http://www.writing.eng.vt.edu/ |
| http://www.calstatela.edu/library/guides/3mla.pdf |
| Oral Presentation 1, Gantt Chart |
| Week 16: Final Presentation (Oral presentation 2 & Demo) |

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operations. Thus a successful creation of a GUI such as that shown in Figure 1, demonstrates that the student (a) understands the importance of creating user-defined functions or modules that can be easily linked with other functions, and (b) can perform fundamental linear algebraic operations. Students are encouraged to use GUIs when presenting solutions to other laboratory exercises. About fifty percent of the students choose to use GUIs.

Basic Stamp Projects

The open-ended projects assigned in the last few weeks will now be discussed. The instructor presents the guidelines for the projects and the entire class provides inputs in the preliminary phase. In some semesters multiple microcontroller-based projects are provided by the instructor, and depending on the complexity of a project, teams may consist of two, three or four students. At the end of each semester every student is required to give feedback on the entire process. This feedback is used to improve the guidelines for subsequent semesters. Microcontroller-based projects require the use of the Parallax Basic Stamp microcontroller.

Background

Robots are used in many engineering design situations. In particular microprocessor control is basic to understanding how non-standard features such as servo control, programmable action, position sensing, response and PC-interfacing work. Microprocessor control is one of the foundation elements in mechatronics, a methodology used for the optimal design of electromechanical products. Mechatronics is multi-disciplinary, and allows today’s engineering students to gain and use knowledge across the board in electrical, mechanical, and computer sciences, and in information technology.

In ME175, the students have been introduced to the Board of Education Basic Stamp 2 microcontroller and the Board of Education robot, Boe-Bot. A 5-week semester project allows students to demonstrate their programming skills by using computer control to maneuver two robots while performing a repertoire of actions. Videos of student projects completed since fall 2000 can be found at the author’s web site(7). Four examples of student projects are now presented. All projects may exhibit some of the additional features shown in Table 2 with a limitation that only materials supplied by or agreed upon by the instructor and class members are permitted.

Table 2. Other desirable features for each project

<table>
<thead>
<tr>
<th>Communication with PC or Cell phone</th>
<th>Line following</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance Detection</td>
<td>Light Sensitive Navigation</td>
</tr>
<tr>
<td>Drop-off or Edge detection</td>
<td>Navigation with Infrared</td>
</tr>
<tr>
<td>Infra-red detection</td>
<td>Obstacle detection</td>
</tr>
<tr>
<td></td>
<td>Sound and/or light</td>
</tr>
</tbody>
</table>
Project#1 Fall 2008: Each group of students must design autonomous vehicles to scatter and collect plastic balls. A sample board for the competition is shown in figure 2; color may be white or brown.

Two Boe-Bots are required and time limit to complete all tasks is 3 minutes.

BoeBot1:
1. Starts at least 60 cm away from the triangular ball depository area carrying 6 plastic balls. Ball diameter is 3 cm.
2. Carefully deposits all 6 plastic balls in the triangular area whose boundaries are marked by tape. Balls must be contained within the triangular area situated on the elevated board (elevation is 15 cm).
3. Carries a manipulator to scatter the balls.
4. Scatters the 6 plastic balls so that each ball crosses a line located 30 cm from the edge of the board. Any ball that enters a hole or rolls off the board will be randomly placed in front of the line as shown in the figure.

BoeBot2:
1. Starts in a designated location (see figure).
2. Finds a ball without touching any other ball.
3. Deposits the ball in any hole.
4. Repeats steps 2 and 3 at least once.
5. Returns to start location.
6. Does not fall off the elevated board.

Project by Group 11(8) – Fall 2008

Figure 3 shows Boe-Bot#1 designed to deliver the balls to the table and perform ball scatter.
The design and programming of Boe-Bot #2 was the most efficient of all designs presented. The robot accurately accomplished ball retrieval and deposit of ball repeatedly. The sensors and devices below the image in Figure 4 are used for ball detection and ball capture and the sensors on the right-hand side are used to navigate to the hole after ball capture. The schematic diagram for Boe-Bot #2 is shown in Figure 5.

Project#2 Spring 2008: Test-tube Retriever

This project was inspired by a robot workcell that consists of two robots Puma 560 and IBM 7575, and a conveyer system found at Professor Harry Cheng’s(6) Integration Engineering Laboratory at the University of California at Davis. Some modifications were made as shown in the project guidelines. A team of four students worked on this project.

Goals: Boe-BotA should remove a test-tube full of beads off a rotating platform and pour the beads into another test-tube held by Boe-BotB. Boe-BotB then returns the test-tube back to the rotating platform. Repeat the process.

Guidelines:

a) Maximum project area: 48 inches x 48 inches
b) Elevation of rotating platform: between 4 and 6 inches

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c) 3 test-tubes of beads equally spaced on rotating platform  
d) Maximum time to complete process: 3 minutes  
e) Parallax QTI sensors are not allowed


The group was able to overcome several challenges in order to successfully accomplish the project. The biggest challenge was navigation since QTI sensors were not allowed. A custom printed circuit board (figures 6 & 7) with photoresistors, light-emitting diodes and resistors was developed. The fabrication of the arm/clamp fixture for Boe-BotA (Figure 8), required utilizing one servo to satisfy both the vertical and rolling motions.

The process was successfully repeated and only one bead fell out during the transfer process (Figure 9). A video of this project can be found at the author’s web site[7].
In Fall 2007 two projects (#3 and #4) were assigned. Each group of students must select either the **basket ball shooting machine** or the **fire-fighting team**. Although the overall project is open-ended the main goals decided upon by the class are stated below.

**Project #3 by Group 7(10): Basket-ball Shooting Machine**

**Goals:** A container with at least one ball is transported by Boe-BotA. Boe-BotA traverses the edge of the court and parallel parks between two obstacles. Boe-BotB acquires the ball from Boe-BotA and shoots the ball into the hoop. At least one ball should enter the hoop in a maximum of three attempts.

**Guidelines:**

1. Minimum basket-ball court dimensions: 48 inches x 24 inches
2. Elevation of basket-ball hoop: ≥ 10 inches
3. Maximum diameter of basket-ball hoop: 4 inches
4. Minimum diameter of ball (ping-pong) 1.5 inches
5. Minimum distance from hoop at which ball is released: 12 inches.

This project was designed to test the robot’s ability to precisely and repeatedly launch an object.

The navigation was accomplished using QTI sensors for line following. Boe-BotA (Figure 10) delivers the ball to Boe-BotB (Figure 11) and proceeds to the basket to catch the ball. This robot is capable of releasing one ball at a time. Boe-BotB receives a signal from Boe-BotA that triggers when it should move up to the shooting line that is located 3 ft from the 12-inch high basket. After launching the ball, Boe-BotB then signals to Boe-BotA that the ball has been launched before returning to the start position to receive another ball. The transfer of the ball from Boe-BotA to Boe-BotB was accurately and smoothly done. This team of three students
programmed Boe-BotB to shoot the ball into the basket repeatedly resulting in a continuous cycle.

The trajectory generated by the projectile could be analyzed to obtain the time taken to travel from point of launch to destination. Future projects will include analyzing different speeds with which the ball can be launched and the longest range that can be achieved.

Project by Group 5: Fire-fighting Team

Goals: Boe-BotA detects fire in an area and Boe-BotB has to put out the fire. The area can be a city or a large office or dwelling place. Flame from a miniature candle represents the fire. The fire must be completely extinguished in the shortest possible time.

Guidelines:

1. Area dimensions: width > 4ft, 4ft ≤ length ≤ 10 ft
2. Fire may be from a miniature candle, a flame imitator, or an infra-red sensor
3. Area options (a simulated city, a cluster of buildings, a grid of houses along streets)

This project generated a lot of interest. Group #5 was able to develop a unique idea that involved using transmitters to send a signal from Boe-BotA to Boe-BotB. The computer code was quite advanced as the group members had to research how to use transmitters and receivers, a topic that was not covered in the course. The grid shown had to be accurately mapped to ensure that Boe-BotA knows how many intersections it encounters along the grid as it searches for the fire. It can sense the fire on both sides of the grid. Boe-BotB was programmed to take the shortest path to the fire. Boe-BotB is equipped with a small electric fan powered by a 9-volt battery that rotates until the fire is in its line of sight and then extinguishes the fire.

Some of the programming challenges included: (i) interference from the receiver which gave false directions, and (ii) complexity of code that made the Basic Stamp run out of Electrically Erasable Programmable Read Only Memory (EEPROM). The number of variables had to be reduced and the smallest size possible had to be used for the variables in order to make optimal use of available memory. Also subroutines had to be efficiently written.

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This group’s design was the most efficient of the four groups that attempted this project. The time taken to detect and extinguish the fire was less than two-minutes on a 4-ft by 6 ft area consisting of 16 grids.

Student Feedback

In this section some of the feedback provided by students at the end of the course is presented. Specific questions are not provided but rather students are asked to give comments and improvements that they think will be useful to incoming students and the instructor.

- Feedback 1: Start to work on the project immediately
- Feedback 2: Create a Gantt Chart and assign members to specific task at the start of the project; allow members to choose areas of expertise (the main areas are programming, design, build, powerpoint presentation creation)
- Feedback3: Keep the design simple and have a backup design
- Feedback4: Group members should be ready to collaborate and assist each other especially if one member is running behind schedule
- Feedback 5: Select materials that are inexpensive and will do the task
- Feedback 6: Use resources on the Internet and avoid re-inventing the wheel.

Student recommendations on areas that can be improved by the Instructor

- Feedback 7: Assign the project earlier than the last 5 weeks as instructors in other courses may also assign projects; the robot project is sometimes time-consuming
- Feedback 8: Assign projects that require one robot for a 2-member group
- Feedback 9: Spend an extra lecture on the software features such as pulse-width-modulation (PWM) and Electrically Erasable Programmable Read Only Memory (EEPROM)
- Feedback 10: Give the same project to the entire class, it makes evaluating the projects easier.

Implementation to Date – A Response to Student Feedback

The response to student feedback 7 – 10 follows:

- Response7: In the current semester, spring 2009, PBasic is introduced in week 3 (see Table 1 Course Syllabus). The project is assigned in week 12. It is preferable for the students to concentrate on the project in the last few weeks.
- Response8: After some discussions the conclusion is that the primary concern is the cost of the Boe-Bots. A Boe-Bot is available for loan to a group of two members. In extreme circumstances the class may allow the use of one-robot but then the project has to be modified.
Response9: As shown in Response7 above PWM and EEPROM are now being addressed and extra help will be provided as needed.

Response10: This change was made last semester (Fall 2008) and it worked quite well. There was a lot of collaboration among groups even though each group’s project maintained the unique characteristics presented in the preliminary phase.

Conclusions

The inclusion of projects dramatically increases students’ interest in the subject. Even at the beginning of the course students express their anticipation in the hands-on robot designs that the course offers. Faculty from the college of engineering, students from other disciplines, friends and families frequently attend the end-of-semester presentations. The graphical user interface is used in other courses and students appreciate how they were developed. Some students have applied these GUIs in courses such as statistics. The overall passing rate has greatly improved. It has been observed that the focus on numerical methods as a means of providing a foundation to real-world problem solving definitely complements the project approach. Students now understand the notion of acceptability of solutions, and are aware of errors encountered in computing and how it relates to real-world designs. The team approach reveals to each member that the learning experience consists of frustration, compromise, and ultimately success. Future development already approved by the department of mechanical engineering includes offering a similar structure in an introduction to computer programming course so that students may appreciate at the onset why understanding programming concepts is essential for engineers. Emphasis will also be placed on communication between MATLAB and the Basic Stamp2. This approach establishes a most important link between theory and implementation.

Acknowledgments

Project examples presented in this paper were contributed by the following students: Aman Bains, Rod Baybayan, Alan Camyre, Ryan Dunish, Ian Hellstrom, Robert Jolley, Drew Mast, Cheng Moua, Matt Morrison, Garret Snedeker, Dustin Sutherland, Justin Pettenger, and Hung Tran.

References

Biographical Sketch

Estelle Eke received a B.S. degree in aeronautical and astronautical engineering from Purdue University, an M.S. in mechanical engineering and materials science from Rice University, and a Ph.D. in aeronautical and astronautical engineering from Rice University. She worked for two and half years in the Spacecraft Navigation Section at the Jet Propulsion Laboratory in Pasadena, and then taught for two and half years in the Department of Aerospace Science Engineering at Tuskegee University before joining Sacramento State University. While at Tuskegee University, she received the Teacher of the Year award in Aerospace Engineering for two consecutive years. At Sacramento State, she was named Outstanding Teacher in the College of Engineering and Computer Science in 2000. She is currently Professor of Mechanical Engineering and teaches courses in the general areas of dynamics and control. Her research interests are in optimization and robotics. She also serves as a design judge for First Robotics competitions at the elementary and high school levels.
Redevelopment of a Systems Engineering Course into Blended (Hybrid) Mode

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Abstract
Research in the area of teaching methods supports the use of an appropriately designed blended mode to supplement a traditional lecture format. A blended or hybrid course, by definition, reduces face-to-face (f2f) "seat time" so that students may pursue additional teaching and learning activities outside of class, typically online. This paper describes the process and experiences of the redesign of a systems engineering course into a blended course. To be successful, the redesign requires careful application of pedagogical concepts and continuous improvement using an understanding of how students learn. This paper is a status report of an ongoing effort.

Introduction
While distance education programs have exploded in recent years, a new trend within the field has emerged: blended or hybrid courses. A hybrid course builds on a traditional, face-to-face course incorporating online elements, using the same course management software that underpins courses taught entirely online. This model can appeal to a wide range of instructors, even those who are critical of online learning, and can be used to improve a variety of courses or solve particular problems. Some universities have used the hybrid model to solve classroom space shortages, to improve communication between students and instructors in large classes, and to address students' needs for computer and technology literacy (Lindsay, 2009).

There is a wide range of interpretations of how to define blended learning (Boyle, 2005; Whitelock & Jelfs 2003; Driscoll 2002). These arise partially from the different motives that underpin the use of a blended learning approach. These vary from cost-saving considerations to pedagogical considerations of producing more effective methods of learning. At the base of these descriptions is usually a mixture of asynchronous-based (online) learning and traditional face-to-face learning.

The intent of this paper is to describe a method for redesigning an existing, lecture-only f2f course into a 50-50 blended course and to share lessons learned in the process.

Background

Existing Systems Engineering Course
Aerospace 510 (Systems Engineering I) is an introduction to the system engineering (SE) discipline for graduate students. SE is truly the integration and orchestration of all engineering activities to meet customer needs. One widely-accepted definition of SE is given by the Department of Defense (2001).
Systems engineering is an interdisciplinary engineering management process that evolves and verifies an integrated, life-cycle balanced set of system solutions that satisfy customer needs.

While SE is a traditional topic in many engineering programs and some universities offer entire programs in SE, we began offering this course in 2005. Since then, the course, offered approximately twice a year, has slowly evolved and developed into a traditional, 4 hours/week, 40 hours/term lecture course. The course is open to all graduate students across the college of engineering, but is comprised primarily of aerospace, industrial and civil engineering students.

I have taught this course for 6 times, both in a conventional classroom setting and with the addition of remote students in an in-class/distance-learning combined setting. While the lecture content was relatively well-developed, there were many opportunities for continued improvements. For example, a rich selection of case studies exists to emphasize both system development successes (i.e., Boeing 777) and failures (i.e., The California Statewide Automated Child Support System). While a traditional course allows for outside reading and in-class discussions, many of the case studies have engaging multimedia components that spur other learning opportunities for students. In a traditional setting, it is not feasible to employ the full potential of these opportunities.

Focused Continuous Improvement

The mission of the Center for Teaching and Learning (CTL) is to enhance teaching and learning by providing an environment and resources to:

- Create opportunities for faculty and staff to enhance teaching and learning skills.
- Promote cross-discipline discussion and collaboration, sustain an interactive community of faculty and staff learners.
- Encourage awareness of issues that affect both the academic community and its disciplines.
- Help faculty and staff maintain currency in their chosen fields.

The CTL provides teaching and learning support for faculty, interacts with colleges and departments, conducts workshops and classes, provides learning communities, publishes newsletters, and administers grants (Cal Poly, 2009). The current course redevelopment effort was made possible by the support of the Cal Poly CTL.

Backward Design

Very few of us, as engineering educators, have had a formal course in pedagogy. Therefore, in addition to the challenging task of developing new and improving existing courses, we also have to battle with our lack of formal training in the area of course design. However, there is a rich field of instructional design literature from which we can draw.

Backward course design is one method that can guide instructors as they struggle with designing their own courses or even an individual lecture (McTighe & Wiggins, 2005). The steps in backward course design include: (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, we 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 Design (McTighe and Wiggins, 2005)

Backward design begins with the end in mind and asks the questions: What enduring understandings do I want my students to develop? How will my students demonstrate their understanding when the unit is completed? How will I ensure that students have the skills and understand the concepts required on the summative assessment?

Instructors pose these questions at the earliest stages of the course planning process. By beginning with the end in mind, instructors are able to avoid the common pitfall of planning forward from activity to activity, only to find that some students are prepared for the final assessment while others are not. Using backward design, teaching for understanding, and requiring students to apply and demonstrate their learning are not new concepts. Many of the best instructors have been using this approach, even if they didn't have a name for it.

What should students know and be able to do?
In stage one we consider our goals, examine established content standards and review curriculum expectations. What content is worthy of enduring understanding? Due to the limited amount of time in a quarter, we must make choices and priorities.

How will we know if students have achieved the desired results?
Begin with the question: “What would we accept as evidence that students have attained the desired understandings and proficiencies?” Before designing specific units and lessons, consider up front how the instructor will determine if students have attained the desired understandings.

What activities will equip students with the needed knowledge and skills?
Finally, ask the question: “What materials and resources are best suited to accomplish these goals?” With clear identified results and appropriate evidence of understanding in mind, it is now the time to select and fully develop the most appropriate instructional activities.

Method
In the fall of 2008, I enrolled in a CTL Technology Initiative-Phase I course. The intent of this course was to help faculty (the “students” in the course) understand and develop a blended course. The objective was accomplished by providing a blended course to the enrolled students (A blended course to teach how to develop a blended course, if you will). The students and instructors met F2F each week, followed by asynchronous assignments to complete both individually and in collaboration with fellow classmates, completed online using Blackboard. The instructors of the Phase I course used backward design and other pedagogical methods concurrently as they taught those concepts as the content of the course.
For example, one of the learning objectives of the Phase I course was:

- Participants will be able to plan the method of teaching based on objectives and assessment that will facilitate learning using technology.

Lessons were focused on meeting this learning objective. The students then performed small planning pieces of their respective courses and submitted those plans for evaluation by the instructors and fellow classmates.

**Backward Design of Aero 510**

At the completion of the Phase I course, the basis of the SE course redesign was in place. In the weeks to follow, the model of backward design and appropriate uses of technology to enhance student learning were implemented using the existing content of Aero 510 as a baseline.

For example, in Aero 510, one of the topics is requirements management. *(Requirements management is the process of eliciting, documenting, analyzing, prioritizing and agreeing on requirements and then controlling change and communicating to relevant stakeholders)* (Blanchard & Fabricky, 1990). In the process of redesign, the identified learning outcomes were explicitly identified:

After successfully completing this module, students will be able to:

- Describe relevant characteristics of requirements
- Evaluate requirements for adherence to relevant characteristics
- Describe the requirements discovery process
- Define requirements management
- Collaboratively write requirements

The next step, determining acceptable evidence, was performed. For the learning outcomes above, acceptable evidence was identified as:

- Complete and submit homework questions related describing relevant characteristics of requirements
- View flawed requirements and submit improvements
- With a classmate or instructor, review the details of the requirements discovery process
- Submit a one paragraph definition of requirements management.
- In collaboration with a 5-person team, create a solution-independent requirements document for the transportation requirements for package delivery driver.

Finally, lessons and activities were planned to accomplish the learning outcomes, verified by observation of the completion of the acceptable evidence. For example, in F2F lecture, approximately 30 minutes of lecture time was dedicated to describing relevant characteristics of requirements, which include:

- A requirement should state “what” is required, not “how” it is to be accomplished
- A requirement should be stated in such a way that it can be verifiable
Each requirement should be “atomic” (requires exactly one thing)
Requirements should use precise and grammatically correct language

To augment the lecture, two reading assignments were given to reinforce these core concepts and a 10-minute video clip was posted that emphasized Boeing’s requirement development during the 777 development program.

Following the student’s completion of learning assignments, they were presented with a list of intentionally flawed requirements statements and asked to identify the flaw and submit recommended improvements. These submissions were evaluated as acceptable evidence of achieving the original learning outcome: evaluate requirements for adherence to relevant characteristics.

The backward design process of identify desired results -> determine acceptable evidence -> plan learning activities was repeated for every topic and module in Aero 510. The output of this process is tightly-packed, efficient teaching plan with lecture, reading and support materials that support the learning objectives.

Discussion
Ironically, this method of curriculum development follows an abstracted systems engineering process: clearly identify the requirements, and then plan all subsequent activities to verify the requirements will be met. Backward design establishes what an instructor wants to achieve (the requirements), determines the acceptable evidence to prove those requirements are met (verification) and directs the development activities accordingly (project planning). Further, many of us developing engineering curriculum, already do some or many of these activities either intuitively or by pulling from our experiences. This method of development may or may not deliver and effectively designed course. However, using the explicit, controlled backward design process, we are increasing the likelihood that our efforts will achieve the desired results.

Benefits Observed
While I strongly feel that implementing backward design has improved my course and my teaching effectiveness overall, I have not attempted to quantitatively measure the improvements. This is, of course, a failure of a standardized continuous improvement effort (lack of technical performance metrics and a baseline of these metrics). However, I can use my own qualitative observations to communicate a few of the improvements I have seen:

- Students appreciate and respond positively to having explicit, well-defined requirements for assignments. If requirements are written as “what” and not “how”, then we as instructors can still challenge and require students to think and develop solutions.
- Students like options. Having asynchronous, online assignments, I can post a variety of materials and allow students to choose. While this makes guaranteeing exact consistency in assessment impossible, this has not yet become a problem.
- Students are engaged by differing content delivery methods. The technology allows for many differing methods to deliver content. For example, a short documentary video on Space Shuttle drop tests from a Boeing 747 to reinforce and illustrate verification testing methods is much more engaging than merely describing these tests with static photographs in lecture.
Students like asynchronous assignments, both for the variety of the assignments and for the fact that they can work on and complete the assignments on their own schedules.

**Lessons Learned**

The CTL provided excellent instruction and support in preparation for developing this course. However, there was much to learn not only with using the technology to create and manage the asynchronous activities, but also with delivering content and explaining the varied tasks to students. For most of the students, this was their first experience with a blended course. Mistakes and lessons have, of course, been learned along the way:

- Technology issues: It seems that no matter the amount of preparation, there will always be students that struggle with the technology. Sometimes it is the student’s inexperience or unwillingness to try something new or it is simply some obscure detail that prevents the technology from working correctly. My lesson is to just accept that this is going to happen and deal with each case with as much patience and a willingness to provide “work-arounds” as possible.

- Explicit communication of expectations: Even with my understanding of proper requirements characteristics, I still missed sometimes. My lesson is to expect students to question a poorly written requirement and to plan on making modifications to it as errors are understood.

- Anticipating varied student schedules and procrastination: When students are working collaboratively on asynchronous activities, it doesn’t work to have a single due date at the end. Some students perform work early and wait for the others to contribute. However, as I should have anticipated, some students wait until the last possible minute to begin the assignment. This leaves no time for there to be any real, iterative collaboration. My lesson is to have intermittent checks, which require all students to collaborate several times throughout the assignment.

- Need for better assessment techniques: It is difficult to get everything just right the first time. I feel some of my assessment methods are inappropriate for the assignment or just not well-developed. My lesson is to practice continuous improvement by identifying the trouble areas and working to slowly improve those areas by small iterations.

- Time commitment to develop a blended course: Finally, it is often stated in the literature and by my colleagues at the CTL: it takes a lot of time to redevelop a course using backward design and blended course concepts and technology. My lesson is to listen to their estimate, then double it.

**Conclusion**

The development of a blended course requires not only a mastery of the related technology, but also a fundamental understanding of curriculum design. Perceptions of a blended course may be that it is simply moves the delivery of course content online. We have likely all witnessed examples of poorly implemented use of technology and realize that, in fact, not all teaching-related technology is useful. However, if properly designed, implemented and delivered using an established method such as backward design, the use of technology can improve the effectiveness of our teaching, even if the improvements are qualitative in nature.

Backward design was applied to the redevelopment of an introduction to systems engineering course. This first iteration was successful from a qualitative standpoint, but this is not the end of
the effort. The course deficiencies identified will be addressed and corrected. This paper is merely a status report of ongoing efforts that will continue as long as this course is taught.

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Biographical Information

Dr. Kurt Colvin joined the faculty at Cal Poly in 2000 and is currently an Associate Professor in the Department of Industrial and Manufacturing Engineering. He received a Ph.D. in Industrial Engineering from Oregon State University. Prior to Cal Poly, Dr. Colvin had 5 years of systems engineering experience and 5 years of research and collaboration with NASA Ames Research Center. He is a registered Professional Engineer in California. Dr. Colvin’s major research interests include systems engineering methods and education, aviation human-factors and manufacturing technologies. His recent projects include building an experimental airplane with Cal Poly students, studies of pilots’ visual scanning performance, and development of distance education-based systems engineering graduate courses. He is also an avid commercial-rated pilot.
Laboratory Projects Appropriate for Non-Engineers and Freshman Engineering Students

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Engineering Faculty

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Professor of Engineering

Introduction

The engineering departments at Hope College and Mission College both offer technological literacy courses targeted to non-science majoring students. These lab-based general education courses are designed with mechanical dissection and “make-and-take” lab projects that represent core technology.

These technological literacy courses are often referred to as “How Stuff Works” classes, because the focus is how and why core technology works as it does. Students are exposed to the scientific principles underlying the technology, and with this the students build or modify devices to work in a manner that satisfies a human desire, which is the engineering component.

Lab projects are constructed primarily with common, ordinary parts typically found in local retail stores. The use of simple parts helps to reduce abstraction and clarifies the underlying science of the technology. Engineering is explained primarily with natural language, demonstrations, teacher modeling, and hands-on lab projects. The lab projects either require students to take apart a device and analyze the functional parts (mechanical dissection) or build from scratch a new device (i.e. “make-and-take” projects).

Core Technology is defined as technology that is familiar to students as users. Core Technology is also technology that appears repeatedly in many engineered systems. Examples of Core Technologies are 1) a speaker, 2) a radio, 3) the LED, 4) the transistor, 4) the lever, 5) the internal combustion engine, 6) a DC motor, etc. These technologies are so familiar in everyday systems that students have a starting point from which to build their knowledge.

All people can and should understand the workings of common core technologies and have a basic understanding of the underlying science. With a “How Stuff Works” class, students are given a foundation that can be applied later to learning about other technologies not covered in the course. The benefits to having a technological foundation are clear – many important issues of our time have a technological component. With a proficient understanding of current technological issues, citizens could be more participatory and effective members of society.
Much work has been done through NSF funding to bring engineering, science, and technology to the public, but teacher materials for the college level are primarily available in electronic form. Support for faculty needs to extend beyond electronic file sharing to include supplying ‘starter’ kits that contain all the parts needed for students to build a project.

The Hope College – Mission College collaboration, with support from the National Science Foundation, is providing kits to faculty at other institutions and assessing if putting equipment and materials into hands of teachers is an effective means of getting more lab projects adopted into technological literacy and freshman engineering courses.

Why is Technological literacy important?

The National Academy of Engineering (NAE), as stated in Technically Speaking, describes “Tech Lit” as

> Technological literacy encompasses three interdependent dimensions – knowledge, ways of thinking and acting, and capabilities. ¹

Technology or the human-built environment is seen as encompassing four main content areas: Technology and Society, Design, Products and Systems, and Core Concepts and Connections.²

“How Stuff Works” classes falls into the Core Concepts category. The wide coverage of fundamental technologies makes these courses a starting point for college students who wish to have a better understanding of the broader technological world.

The NAE goes further to set the following goal:

> The goal of Technological literacy is to provide people with the tools to participate intelligently in the world around them. ¹

Technology has become more widespread and essential in our society now than ever in the past, and yet most people have a poor understanding of the technology they interact with. Devices are smaller and unserviceable, interfaces simplify and hide the technology so that users do not need to understand the technology in order to use it, and much of new technology today is happening at the microscopic level. All of these facts add separation between the end-user and the technology. The result is that collectively citizens are becoming less aware of technology but at the same time more dependent on it. This chasm between dependence and understanding needs to be addressed.
The NAE makes a strong case for greater public understanding of technology in Technically Speaking by stating

Democratic principles imply that decisions affecting many people or the entire society should be made with as much public involvement as possible. As people gain confidence in their ability to ask questions and think critically about technological developments, they are likely to participate more in making decisions. ¹

The importance of an informed public on the health of the republic was stated numerous times by Thomas Jefferson. Jefferson was quoted as saying,

“If a nation expects to be ignorant and free in a state of civilization, it expects what never was and never will be.”

Technological literacy should be as important to our students as cultural literacy. A foundation of technological literacy not only helps explain the workings of technology but illustrates how fully integrated technology is into the fabric of society.

Technological literacy courses can serve as an educational bridge between the liberal arts and engineering. Samuel Florman ³ called for educational bridges to provide a route for engineers to access the arts. In the case of technological literacy courses, they are the bridge that gives the non-science student access to engineering and technology.

**Types of Technological Literacy courses**

Engineering departments on a number of campuses have begun to offer technological literacy courses for non-science majoring students. There are four standard models of technological literacy courses as explained by John Krupczak and Dave Ollis: ⁵

1. The Technology Survey course.
2. The Technology Focus Course that focuses on a particular technology area.
3. The Technology Creation Course (a course with design emphasis).
4. The Technology Course that Critiques, Assesses, Reflects, and/or Connects

Hope College and Mission College both offer Type-1, the Technology Survey Course designed for non-science majors.
Course Format and Lab Projects

Our Type-1 survey courses have two interconnected parts when covering new core technologies:

First, there is a lecture designed around small learning increments\(^6\) about the science and technology specific to what students will build and see in the lab project. This is done so that students have a basic understanding of how and why the technology works before doing the lab. This is done through lecture and demonstrations.

Second, the students dissect or build a device. In doing this the students reinforce lecture information through observation and experimentation. Lab questions are designed to require students to experiment with the device by doing simple tests during the lab. After seeing something work, most students are more internally motivated to explain on their own the workings of the technology.

Direct instruction and lab parts must connect together. Connections can be made by reviewing a second time the lecture material during and after the lab.

The risk of not connecting lecture with lab is two-fold. Without direct instruction from the instructor, students will robotically assemble a device (i.e. this becomes the “cook-book” lab that has limited impact). Without the laboratory component the lecture runs the risk of being one-way and flat, and student learning becomes overly passive. Ensuring that lecture and lab fit together throughout the course gives students the connections linking the science to the technology.
Some of the labs being used in the Hope College and Mission College courses are:

<table>
<thead>
<tr>
<th>Dissection Lab Projects</th>
<th>Core Technology</th>
<th>Related Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Toy Car with Internal Flywheel</td>
<td>Energy Storage using Flywheel; Cams; Mechanical Advantage using Gear Reduction Box</td>
<td>Kinetic Energy; Rotational Inertia; Work; Friction; Torque</td>
</tr>
<tr>
<td>2. Mechanical Alarm Clock</td>
<td>Escapement; Energy Storage using a Spring; Hair Spring and Balance; Gears; Portable Time Pieces</td>
<td>Periodic Motion; Spring Potential Energy; Frequency, Sound; Pendulum (comparison)</td>
</tr>
<tr>
<td>3. Four Cylinder Internal Combustion Engine</td>
<td>Pistons; Valves; Crank Shaft; Cam Shaft; Timing Belt; Fuel Injection; Bearings; Engine Head and Block; Seals &amp; Gaskets</td>
<td>Thermodynamics; Linear to Rotary Motion; Friction; Combustion; Efficiency</td>
</tr>
<tr>
<td><strong>“Make-and-Take” Lab Projects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Speaker</td>
<td>Speaker; Voice Coil; Diaphragm; Permanent Magnet</td>
<td>Electricity &amp; Magnetism; Electromagnet; Sound Waves; Vibration</td>
</tr>
<tr>
<td>5. DC Motor</td>
<td>Electric Motor; Rotor and Armature; Commutator; Brushes; Power Supply</td>
<td>Energy Conversion; Conductors &amp; Insulators; Generators (comparison); Torque; RPM</td>
</tr>
<tr>
<td>6. AM Radio</td>
<td>Radio; Antenna; Diode; Modulation methods; Tuner Circuits; Filters; Carrier Waves; Uses of the Electromagnetic Spectrum</td>
<td>Electromagnetic Waves; Electromagnetic Induction</td>
</tr>
<tr>
<td>7. Audio Amplifier Circuit</td>
<td>Transistor</td>
<td>Semiconductors</td>
</tr>
<tr>
<td>8. Battery Recharging Unit using Solar Cells</td>
<td>Photovoltaic Solar Cells; Batteries; Designs for Efficiency</td>
<td>Energy Capacity; Power; Voltaic Cell; Series and Parallel Circuits</td>
</tr>
<tr>
<td>9. LED Book Light</td>
<td>Light Emitting Diode; Switches; Incandescent Bulb (comparison)</td>
<td>White Light vs. Colored Light; Electricity; Energy Conversion; Ohm’s Law</td>
</tr>
</tbody>
</table>

Table 1
There are many other labs that would be appropriate for a Type-1 survey course. We chose those projects in Table 1 with the following goals in mind:

a) For items used in dissection, it is important to choose devices that will allow students to do functional decomposition. By taking the device apart the students can see the role of each sub-part and how it interacts with the other components. Functional Analysis helps students to transfer their understanding to other devices that utilize similar elements or core technologies.

b) Labs should be done individually. Each student constructs his/her own device. Although students are encouraged to help each other, individual projects usually means that all students are taking ownership in the project, especially if the lab project is something students will take home and keep.

c) Labs should require some manual work because learning and retention is enhanced when students do something with their hands.

d) Labs should be as simple as possible while still including all the fundamental components of a working device.

e) Create labs using simple, ordinary parts. Avoid using parts that are specially manufactured for a specific application as this will lead to a level of abstraction that is not necessary and may confuse some students.

f) Find labs that represent core technology – building block devices that are used repeatedly in other systems. Projects should be either real devices used for dissection or if it is a “make-and-take” project the device constructed should do something useful. Projects should not just verify a scientific theory.

g) Choose labs that can be connected together, either conceptually or literally. The speaker, radio, and audio amplifier are connected together so that students take away a complete AM radio.

h) Choose lab projects that can be analyzed and described mainly with natural language (i.e. minimal math).

i) Simplify labs and the directions such that every student who tries can complete the lab during the allotted time.

j) Use inexpensive parts.
Some Barriers to Offering Technological Literacy Labs

Aside from possible state level or institutional resistance to engineering as general education, there are other real barriers that may increase the effort of starting up a lab-based technological literacy course.

Budget constraints may limit lab projects. The semester cost for our technological literacy courses is approximately $55 per student. Currently there are only a few appropriate texts and even fewer lab manuals designed for a Type-1 technological literacy course. Due to the lack of instructional materials, faculty must develop their own labs and lectures. Lab development may be burdensome because:

a) Some trial and error is needed to fine tune lab projects and make labs affordable.

b) In order to achieve a breadth of labs covering a wide range of engineering, faculty must develop labs outside their discipline area.

c) Time may be limited because of heavy teaching loads, especially at small colleges.

d) It takes time to identify reliable parts vendors, such that a successful lab can be sustained.

e) Lab preparation is more intensive because of the individualized make-and-take model which demands more purchasing and organization. The lab technician may resist taking on different duties that do not fit the paradigm of existing science labs.

No one barrier is insurmountable, yet most faculty will encounter some aggregate of these barriers making course development challenging.

Despite the obstacles, the rewards for offering a technological survey course are great. By doing something challenging (i.e. coming up with good labs), we offer our students a valuable course with a significant added value that is hard to replicate outside our networks. The experience of constructing a working device such as a radio, or hands-on contact with an actual car engine, provides students with an understanding of technology that cannot be replicated by clicking through an online virtual laboratory simulation. Doing this ultimately should give our students a competitive advantage in the global marketplace.

The Hope College – Mission College collaboration is investigating the viability of sharing lab materials in order to make it easier for faculty to start up technological literacy courses or to introduce these labs into their existing freshman engineering courses.
Lab Sharing

The internet has made materials in electronic format very easy to share. Lab equipment and lab projects cannot be shared in the same way. In order to adopt a lab, the teacher must acquire the materials and equipment, work through the project, and scale the lab to work in a setting of approximately 30 students. Often the “devil is in the details” and the devil is not seen until the lab project is sitting in the hands of the teacher. For this very reason equipment vendors set-up and demonstrate their products at trade shows or conventions. Pictures and videos do not “sell” equipment to consumers nor do they to teachers.

Recognizing this commits us to finding processes that will put materials and equipment into the hands of teachers.

The Hope College – Mission College collaboration is investigating the viability of sharing lab materials using our common shipping infrastructure, such as the US Postal Service and UPS. A sharing arrangement between colleges may be either on-going or temporary until new faculty become familiar enough with a lab project to prep the lab on their own.

We recognize that some labs are not cost-effective to share on an on-going basis (e.g. sharing a car engine). In such cases a one time share arrangement can be just enough to train the faculty and break the barrier of unknown. Having the actual equipment and using it in a lab setting gives faculty the “gestalt” needed to see the value of the lab. Having the lab equipment once also allows the faculty to better assess what is entailed in acquiring the lab equipment.

Hope College and Mission College have provided student kits for the following courses:

- Computers, Networks, & Emerging Technologies: CNET 114 – “How Technology Works” at Ohlone College, Fremont, CA
- Engineering: ENGR 10 – “Introduction to Engineering” at Las Positas College, Livermore, CA
- General Engineering: ENGR 10 – “Introduction to Engineering” at San Jose State University, San Jose, CA
- Engineering: ENGR 5 – “Engineering as a Profession” at Cabrillo College, Soquel, CA
- Engineering: ENGR 01 – “Introduction to Engineering” at Ventura College, Ventura, CA

Our lab sharing efforts have mostly focused on courses designed for freshman engineering students. This is because most community colleges do not yet have a technological literacy course. Our labs can be used in an introductory engineering course but probably these courses would not offer all of the labs.
As faculty build up a set of introductory core technology labs, the effort of starting up a new technological literacy course should be much less daunting. It is our hope that faculty who do not currently have a technological literacy course will consider creating one and folding these labs into such a course. Our labs at the very least can serve as a baseline from which to develop a technological literacy survey course.

Other Benefits to Lab Sharing

Every instructor has an area of expertise and yet the demand for understanding a wide range of technologies is great, especially in small engineering departments. Sharing labs puts into faculty’s hands a lab they might otherwise never create themselves. This clearly can be seen as faculty development.

There is value in having someone (other than the person who created the lab) test a lab. The feedback allows for lab refinement. As labs are improved upon it is more likely that a set of canonical engineering labs will emerge. A refined set of labs is needed to validate the concept of technological literacy as general education, as well as to ease the efforts required for developing such courses. These labs could then be packaged into lab manuals and begin to help set a standard for technological literacy courses. A well developed repository of course materials is needed for a systemic shift towards accepting technological literacy as general education.

One of the most effective means of assisting faculty with new labs is to actually go and facilitate the lab with the faculty member. Although often infeasible, it is highly worthwhile as this real-time interaction helps build community among engineering faculty.

Lab sharing in no way should be one way. Faculty need to openly share their “secrets” – such as labs, teaching techniques, course materials, etc. if engineering is to mature into a discipline with a well defined role within general education. In order to identify and refine what it is we think all students should know, there needs to be some collective action so that our efforts take root and course materials represent what most faculty think are essential for technological literacy.

Conclusion

It is important that we consider strategies to make it easier for engineering faculty to teach technological literacy to non-science majoring students.

A first step in addressing the barriers to offering technological literacy lab-based courses is for faculty who teach these courses to share their lab materials.

Information and lecture content in electronic format is now easy to come by, yet a lecture-only course makes for “flat” curriculum that can exist anywhere. In order to give an added value to our students, we must do the more difficult task of providing an enriched, hands-on lab experience.
As more hands-on labs for technological literacy courses are used and made available, we should see a canonical set of lab projects emerge. With widespread adoption of labs there is an economics of scale that makes supplying lab materials cost effective for equipment manufacturers. So what is a lot of work today (prepping labs and assembling kits for students) should be significantly less work later as the technological literacy concept takes root.

Non-science majoring students need access to “How Stuff Works” courses in order to gain a foundation in the workings of technology. If students are offered technological literacy courses we will be giving them an opportunity to acquire knowledge of fundamental science and core technologies. With this basic understanding one can continue to investigate the workings of the modern world, thus producing a greater sense of empowerment and comfort with technology.

Acknowledgement

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References


A Framework for Developing Courses on Engineering and Technology for Non-Engineers

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**Abstract**

Americans need a better understanding of the wide variety of technology used everyday. The need for technological literacy is great for both individuals and the nation in general. Creating a population with a more empowered relationship with technology will require a significant and extensive initiative in undergraduate education. Curricula and course materials that are easily adoptable in diverse and varied institutional environments are vital in this effort. The National Academy of Engineering in two reports: *Technically Speaking: Why All Americans Need to Know More about Technology* (2002), and *Tech Tally: Approaches to Assessing Technological Literacy* (2006), outline the characteristics of a technologically literate citizen. The International Technology Education Association (ITEA) and the American Association for the Advancement of Science (AAAS) have also developed standards for technological literacy. The NSF supported a working group lead by the American Society for Engineering Education (ASEE) Technological Literacy Constituent Committee to develop standardized and readily adoptable undergraduate courses on this topic. This group met on March 26-27, 2007 and developed four models to serve as standardized courses on technology. A framework was established for specific course outlines consistent with the content areas established in *Tech Tally* of: technology and society, design, products and systems, and technology core concepts and the ITEA technology topic areas. To make it possible to accommodate the diverse requirements of curriculum committees on varied campuses, the framework offers flexibility to faculty in planning courses within each proposed model while still accomplishing the goals of the standards. This framework will form the organizational infrastructure for creating a repository of course materials as well as an online community for course developers and instructors.
Overview

Technology affects nearly aspect of our lives, and informed citizens need an understanding of what technology is, how it works, how it is created, how it shapes society, and how society influences technological development. How well American citizens are prepared to make technological choices depends in large part on their level of technological literacy. Technological choices influence our health and economic well-being, the types of jobs and recreation available, even our means of entertainment. At a recent NSF Workshop at the National Academy of Engineering (NAE) participants drafted a set of standard course models for teaching technological literacy courses [1,2]. As part of that workshop, a framework for creating courses on technological literacy was developed. This framework can also providing a useful context for discussing standard models for technological literacy courses. A common framework is not only critical for developing effective technological literacy courses but is also a pre-requisite for developing standard course models.

The proposed framework will help faculty develop proficiency in adapting existing best-practice course materials and using standards for defining technological literacy when planning their own courses.

What Is Technological Literacy?

In, Tech Tally [3], the NAE described technological literacy as “an understanding of technology at a level that enables effective functioning in a modern technological society”. This is consistent with E.D. Hirsh’s general definition of “literacy” as “information that is taken for granted in public discourse” [4]. Tech Tally followed a 2002 report by the NAE entitled, Technically Speaking: Why All Americans Need to Know More about Technology. This report explained the importance of being literate about technology in the 21st century [5]. Both NAE reports emphasize that technology, in a broad sense, is any modification of the natural world made to fulfill human needs and wants. Technology includes not only tangible products, but also the knowledge and processes necessary to create and operate those technological products. The supporting infrastructure used for the design, manufacture, operation, and repair of technological devices and systems is also considered part of technology, in the widest sense.

Other efforts have been underway for over a decade to develop standards and guidelines to define what K-12 students need to know and be able to do in regard to technology. In 1993, the American Association for the Advancement of Science (AAAS) published, Project 2061: Benchmarks for Science Literacy [6] and in 1996 the National Science Education Standards were published by the National Academies Press [7], both of these contained sections addressing technology. In 2000 the International Technology Education Association (ITEA) released Standards for Technological Literacy: Content for the Study of Technology [8] with the goal of encouraging educational curricula and programs that would provide technological literacy to K-12 students.

In the Tech Tally report, the NAE identified three major components, also called cognitive dimensions, related to technological literacy. These are knowledge, capabilities, and critical thinking and decision-making. As defined in this report, “The ‘knowledge dimension’ of
technological literacy includes both factual knowledge and conceptual understanding. The ‘capabilities dimension’ describe how well a person can use technology (defined in its broadest sense) and carry out a technological design process to solve a problem. The final dimension – the ‘critical thinking and decision-making’ dimension – has to do with the person’s approach to technological issues” [3]. This dimension enables individuals to ask informed questions about risks and benefits when introduced to a new technology, and to participate in discussions and debates about the potential uses of that technology. Four content areas were also defined. These are: (1) technology and society, (2) design, (3) products and systems, and (4) characteristics, concepts, and connections. In addition, an assessment matrix was created that combined the four content areas (the rows of the matrix) with the three cognitive dimensions (the columns of the matrix), and it is this matrix that lead to the development of the proposed framework reported here.

At the same time, the International Technology Education Association (ITEA) also developed a set of standards (ITEA 2000) for technological literacy, which was published in a report entitled, Standards for Technological Literacy: Content for the Study of Technology [8]. The ITEA 2000 Standards are divided into five main categories that are further sub-divided into 20 specific standards. The five main categories are:

1. Understanding the Nature of Technology
2. Understanding of Technology and Society
3. Understanding of Design
4. Abilities for a Technological World
5. Understanding of the Designed World.

The ITEA 2000 standards were intended to address K-12 students, however it was found that the detail of these standards was helpful in categorizing or classifying content areas that might appear in technological literacy courses for undergraduates as well. The curriculum framework integrates these disparate attempts to define technological literacy and addresses the overlap between the NAE and ITEA approaches.

Engineering and Technology Courses for Non-Engineers.

Some engineering programs have embraced the need to increase the awareness and understanding of engineering as a career by initiating a number of programs aimed at the K-12 audience. An example is the American Society for Engineering Education’s (ASEE) publication, Engineering Go For It,[9] and a website [10] for K-12 students and teachers. The major engineering societies have outreach activities for K-12 [11-14]. At the same time, the ITEA is developing program and assessment standards, and curriculum materials for K-12 education [15]. Engineering departments offering courses on technological topics for non-engineering students are beginning to appear [16].

The recent history of efforts to address the technological literacy of undergraduates can be considered to start in 1982 when the Alfred P. Sloan Foundation established the New Liberal Arts Program (NLA). The goal was to improve undergraduate education in the areas of
technology and quantitative reasoning [17-19]. The Sloan Foundation sponsored development of courses on technological topics for non-science majors. The NLA Program broke new ground in establishing technology as the intellectual peer of science at the college level; however, the experience of the NLA highlighted the difficulty in transfer of courses beyond the founding instructor and campus, and maintaining course offerings after expiration of external funding [20].

After the NLA, some engineering educators have worked on aspects of the broad understanding of technology by undergraduates [21-23]. While the total number of courses reported has been limited [24-53,61-63], results have been significant. Several courses have been successful in attracting substantial enrollments of non-engineering students and existing as long-term offerings [25-29,35-41,44-46,52,53]. Some specific examples include Technology 21, created at the University of Denver [52]. In this course non-engineers study a technological controversy and develop a recommendation for public policy. The course has been taught by the Electrical Engineering Department for more than 14 years and nearly all departmental faculty have served as course instructor. The Converging Technologies Initiative at Union College created nearly 30 new or modified courses since 2002 on interdisciplinary technological topics such as pervasive computing and nanotechnology [25,35]. At California State University Northridge, the Manufacturing Systems Engineering Department has taught Computer-Aided Design to campus-wide constituency for a decade [53]. Dartmouth College has had a requirement since 1992 that every student take a course in Technology and/or Applied Science. The majority of these courses are taught by engineering faculty, and some have enrolled as many as 150 students [54].

Simultaneously with these efforts by engineering departments to reach non-engineers, some college and university physics departments have altered their service course offerings for non-majors to emphasize technological topics. Examples include Dudley and Bold’s, “Top-Down Physics” [55], and Watson’s “The Science Concepts behind High Technology” and “Silicon, Circuits, and the Digital Revolution” courses [56]. Bloomfield has developed a course and book entitled How Things Work: The Physics of Everyday Life [57,58]. This approach of technologically-themed and application-oriented science courses for non-science majors incorporates perspectives that are closer to engineering than typical physical science courses. These efforts at presenting the learning of physics through the understanding of modern technology are a marked change from earlier classic works such as Physics for the Inquiring Mind [59] and Physics for Poets [60]. This books avoided technological applications and emphasized philosophical questions and natural phenomena.

These developments show that there is both demand and interest among the non-engineering undergraduate population for courses on technological issues. It also establishes that engineering faculty can develop and teach courses on technological topics to non-engineers. The successful courses taught by engineers span a wide range of institution type and student demographics. They represent campus environments that includes large state universities [45-48,51], private colleges [29,37], technically institutions [49,50], selective schools [26,27,40,43], comprehensive universities [28,44], schools serving working adults [16], and two year colleges [63,64]. The background of the instructors include the major engineering disciplines such as chemical [48], civil [26-28,44], electrical [34,36,40], materials [45,46,61] and mechanical engineering [24,29,31,37]. A feature of nearly all successful technology courses is the need to satisfy some
component of the college or university general education graduation requirement and to be adapted to instructor interests or other aspects of local institutional conditions [65,66].

To determine the research issues regarding the broad understanding of technology by all undergraduates, a workshop on the technological literacy of undergraduates was sponsored by the NSF and held at the NAE in April 2005. There were 42 participants included faculty who had implemented courses on technological literacy for undergraduates as well as representatives from other engineering and non-engineering disciplines. An important outcome from the workshop was the recommendation that: “There is a need for a best practice collection of easily adopted materials.” [67,68].

Most of the existing technological literacy courses were established before the NAE and the ITEA developed technological literacy standards for this topic. Individual instructors determined course syllabi based on their own expertise and inclinations. As part of the 2005 NSF/NAE Workshop, participants found that elements of the NAE and ITEA standards had been incorporated into most of the existing courses; however, no single existing course included all of the standards due to their breadth. With this came the recognition that no one standard course model could be developed for a single course on technological literacy. Rather, four standard course models were established and slated for development as part of the follow-on NSF/NAE Technological Literacy for Undergraduates Workshop, which was held in March 2007 [1,2]. The four standard course models are: (1) Technology Survey Course, (2) Technology Focus Course, (3) Technology Design Course, and (4) Technology Critique, Assess, Reflect, or Connect Course. The framework described here was created to serve as a guideline for developing these standard course models but also as a means to evaluating existing technological literacy courses.

Description of the Proposed Framework

The framework was developed by a team at the 2007 NSF/NAE Workshop on Technological Literacy of Undergraduates [1,2]. The framework takes the form of a 2D matrix that maps content areas – called cross-cutting concepts – to different technology topic areas, as shown in Figure 1. The technology topic areas – the columns in the matrix – are derived from the “Designed World” categories defined by the ITEA 2000 Standards [8] and include an additional “Other” category for areas that the faculty felt were missing from ITEA’s Designed World (e.g., space technology, military technology, materials, entertainment systems).

The rows of the matrix in Figure 1 are cross-cutting concepts group, which are based on the four content areas defined in Tech Tally [3]: (i) Technology & Society, (ii) Design, (iii) Products & Systems, and (iv) Characteristics, Core Concepts, & Connections.

Each cell in the matrix can then be populated with one of four values to indicate the depth of coverage of that cross-cutting concept in each technology topic area:

1. **K → Knowledge**, i.e., the course will provide knowledge about this cross-cutting concept within the context of this technology topic area
2. **C → Capabilities**, i.e., the course will develop capabilities in this cross-cutting concept that can be applied within the context of this technology topic area
3. D → Decision-making, i.e., the course will enable decision-making within the context of this cross-cutting with regards to this technology topic area
4. Blank – Indicates that this cross-cutting concept is not covered to any extent within this technology topic area

These three areas (K, C, D) are based on the three Cognitive Dimensions of Technology Literacy that are defined in *Technically Speaking* [5] and *Tech Tally* [3] where “Critical Thinking & Decision-making” has been simplified to “Decision-making”. The levels (K, C, D) are arranged in terms of their degree of understanding, and it is recognized that higher levels of coverage (e.g., Decision-making) also include the lower levels of understanding as well (i.e., Knowledge and Capabilities). This is consistent with the Bloom’s taxonomy where higher levels of the taxonomy include the ability to demonstrate the lower-level skills as well [69,70].

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<td>Satisfying Human Wants &amp; Needs</td>
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</tr>
<tr>
<td>Energy, Materials, &amp; Information Flow</td>
<td></td>
</tr>
<tr>
<td>Interdependence/Interactions</td>
<td></td>
</tr>
<tr>
<td>Dynamic/Static Systems</td>
<td></td>
</tr>
<tr>
<td>Systems Perspective</td>
<td></td>
</tr>
<tr>
<td>Control &amp; Feedback</td>
<td></td>
</tr>
<tr>
<td>Complexity</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 1. Proposed Framework: The Tech Lit Course Evaluation Matrix*
Using this matrix representation, four types of technology literacy courses are defined. These four types constitute the standard course models that were created as part of the NSF/NAE Technological Literacy Workshop [1,2]:

1. Technology Survey Courses
2. Technology Focus Courses
3. Technology Design Courses
4. Technology Critique, Assess, Reflect, or Connect (CARC) Courses

These are shown in Figure 2. As shown in the figure, it is expected that Survey Courses will span the majority of the matrix with K, C, and D values (see Figure 2a). Due to time constraints and limited course duration, it is not anticipated that any Survey course will completely fill the entire matrix, but it would also be expected that no row will be entirely blank – if it is, then it will not likely qualify as a true Survey course. Meanwhile, a column could be blank if a technology topic area is not covered due to time limits, but a good Survey will likely cover a majority of these technology areas.

Technological Literacy Focus Courses will go into great depth within one or more technology topic areas (see Figure 2b) with a higher fraction of C and D values in that column(s) when compared to a Survey Course.

Technological Literacy Design Courses and Critique, Assess, Reflect, or Connect (CARC) Courses will cover these respective rows in the matrix for one or more of the technology topic areas as shown in Figures 2c and 2d, respectively. It is expected that these courses will also have a higher percentage of C and D values in the corresponding rows – specifically for the detailed cross-cutting concepts within each group – compared to a Survey Course.

Figure 3 shows two examples of the matrix for two courses that were selected from among the 22 existing technology literacy courses surveyed during the 2007 NAE/NSF Workshop [1,2]. In this survey, instructors were only asked to what extent their course covered the cross-cutting concepts at the group level and which technology topic areas were covered, but not to what extent each cross-cutting concept was covered in each technology topic area. It can therefore only be determined to an approximate extent what a Technology Survey Course (see Figure 3a) and Technology Focus Course (see Figure 3b) will actually look like; however, it provides reasonable proof-of-concept for this matrix representation.
Figure 2. Using the Matrix to Define Four Types of Tech Lit Courses

(a) Technology Survey Courses

(b) Technology Focus Courses

(c) Technology Design Courses

(d) Technology Critique/Assess/Reflect/Connect Courses

Figure 3. Instances of the Matrix based on 22 Tech Lit Courses at NAE/NSF Workshop

(a) Example of Tech Lit Survey Course

(b) Example of Tech Lit Focus Course
Description of Current Work

The proposed framework for evaluating technology literacy courses was developed from a survey of technology-focused courses and their developers conducted before the NSF/NAE workshop. This survey asked instructors to compare their existing course to the standards prescribed in Tech Tally [4] and the ITEA Standards for Technological Literacy [8]. The survey only addressed the highest level of the standards and did not include any other aspects of the course such as pedagogy and assessment. The initial survey resulted in 22 courses [1,2]. Current work is broaden the database of courses considered.

The framework shown in Figure 1 will be used as an organizational infrastructure for a web-based repository of best-practice course materials. This online matrix will link to course materials from existing technological literacy courses and enable users to build technological literacy courses by selecting materials from cells, rows, or columns as needed. Contributing educators will be able to populate the matrix by either submitting modules or full course materials. Posting modules or courses will automatically populate one common matrix familiar to all instructors. Users will be able to view individual course matrices or search along one dimension (row or column) of the common matrix. Each matrix cell will have a pull-down menu indicating cognitive level K, C, and D. Users will be able to select the needed depth and post material to, or take material from, any given depth and category. In addition to downloading modules, users will be able to create a complete course online.

The ultimate goal of this work is to fill all cells of this framework with publicly available materials. These materials will then be accessed and used by instructors to develop curriculum for new technological literacy courses. The goal is to streamline the course development process for faculty members at both two- and four-year institutions. Providing a wiki-like environment of best-practice materials open to the public with controlled editing access will help expand participation in this area.

Acknowledgement

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MULTIPOINT REMOTE TEMPERATURE MONITORING AND DATA ACQUISITION SYSTEM USING RF TECHNOLOGY

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Abstract
Embedded system and wireless technology has entered in all aspects of life with variety of useful functions. Wireless communication has changed the way data can be transferred and viewed across locations. Industrial wireless modems use electromagnetic waves to transmit modulated data typically using RS-232 standards. The focus of this work is the development of a “Multipoint Remote Temperature Monitoring and Radio Data Acquisition Embedded System” that is taking advantages from embedded microcontroller, such that interaction and processing with the wireless transceivers and the temperature sensors. The multipoint remote temperature monitoring radio data acquisition embedded system project is implemented using DS-18B20 digital thermometers that gives 12-bit resolution, long range 433Mhz HAC-UM96 with serial interface RF modems and the Freescale HCS12 microcontrollers. This hands-on project aims to use the mentioned hardware for remote data acquisition to monitor and collect temperature and report back wirelessly to be further processed by the embedded microcontroller. One RF modems is used to communicate with the rest of the RF modems and receives the temperature from the remote locations. Project is implemented by using the HCS12 Dragon 12 plus Development Board as embedded microcontroller and “Code Warrior”, an Integrated Development Environment (IDE) for embedded applications. The software is written in ‘C’ programming language using the Code Warrior IDE. The Code Warrior IDE has been developed by Freescale Semiconductor Company[1].

Introduction
Industrial wireless modem accepts serial data (typically using RS-232, RS-422, or RS-485 standards) and transmits it without wires to another device which receives and converts it. Data is sent from one end to the other as if there were a cable. Industrial wireless modems use electromagnetic waves to transmit modulated data. This is done using radio modems as access points. Radio modems are radio frequency transceivers for serial data. They transmit to and receive signals from another matching radio modem. Access points are various junctures in the network that enable wireless network connectivity. The systems that enable supervision of remote processes for data collection are normally termed remote data acquisition or remote data collection systems. These systems are designed using PCs and other processor-based input/output modules conforming to RS-232 and RS-485 standards. Multipoint Remote Temperature Monitoring can create accurate and real time reports in an environments where automated temperature monitoring system is required. Application examples of this kind of
device are in automated temperature monitoring in food industries and health care organizations that are extremely regulated when it comes to proper temperature control[2,3].

**Project Problem Statement**
The main focus of this work has been the development of a remote data acquisition system and embedded microcontroller application in order to enhance and promote experiential learning in undergraduate education for computer engineering students.

**System Architecture**
“Multipoint remote temperature monitoring and data acquisition system using RF technology” is a project taking advantage of wireless technology and mobility of embedded system. It aims to monitor temperature at various zones and report back wirelessly the temperature of these zones to a master node. It is possible for the master node to monitor the temperatures of different zones for controlling purpose. The system architecture overview is shown in figure 1.
This Project takes advantages from embedded system, such that processing and interaction with the wireless transceivers and the various sensors can be integrated on small board that is easily installed in any place and start working once it takes the power.

In this project Dragon12-plus[^4] trainer board is used to perform the following operations:
1. Reading the temperature sensor.
2. Use RS232 serial protocol to load temperature data to the wireless antenna.
3. Use RS232 serial protocol to unload temperature data from the wireless antenna.
4. Display the sent temperature on LCD screen and alerting with sound warning in case of emergency.

The Dragon12-Plus trainer is a low-cost, feature-packed training board from Freescale HCS12 microcontroller family. It incorporates many on-board peripherals that make this board very popular trainer for teaching microcontroller course in universities around the world.

**RF Module (HAC-UM96)**

The HAC-UM96 is designed to be a low cost and high performance radio modem. It is a UART device; data is framed according to the UART standard, very simple to use and is shown in figure 2. HAC-UM96 has a long transmission distance of more than 300m in the visible range. It support dual serial port and 3 interfaces, with COM1 as TTL level UART interface and COM2 as user defined standard RS-232/RS-485 interface[^5,6].

![RF Module (HAC-UM96)](image)

**Figure 2 HAC-UM96 RF Modems**

**Setting of channel, interface and data format**

Before using HAC-UM96 RF modem, the user needs to make simple configuration based on its own needs to determine the channel, interface mode and data format as shown in figure 3. There is one group of 5-bit short-circuit jumper wire (JP2) on the upper right corner of HAC-UM, defined as ABCDE respectively. Assuming the open circuit of jumper wire (without short circuited) is mode 1 and short circuit of jumper wire (with short circuited) is mode 0, then the configuration is as follows: ABC jumper wires of JP2 provide 8 options, and the user can choose to use 0-7 channels through ABC jumper wires. Within one small communication network, as long as ABC jumper wire mode is same, there can be mutual communication.
Channel No. | Frequency       | Channel No | Frequency       
-------------|----------------|-------------|----------------|
CBA=000(0)   | 430.2000 MHz   | CBA=100(4)  | 434.6940 MHz   
CBA=001(1)   | 431.4288 MHz   | CBA=101(5)  | 434.2332 MHz   
CBA=010(2)   | 431.7360 MHz   | CBA=110(6)  | 433.1580 MHz   
CBA=011(3)   | 430.5072 MHz   | CBA=111(7)  | 433.9260 MHz   

Figure 3 Corresponding frequency points of 0~7 channels

The frequency points corresponding to each channel can be adjusted based on the user’s needs.

1 = Unplugging short circuitry  
0 = Plugging in circuitry

The HAC-UM96 pin description is shown in figure 4. The serial ports COM1 (Pin3 and Pin4 of JP1) is fixed as UART serial port of TTL level; COM2 (Pin6 and Pin7 of JP1) can choose non-standard RS232/485 interface mode through D of JP2:

D = 1 (Unplugging short circuitry) COM2 = RS-485  
D = 0 (Plugging in short circuitry) COM2 = RS-232

HAC-UM96 can support no-parity or even parity modes of the serial communication UART, i.e. 8N1/8E1, which can be chosen through E of JP2:

E = 1 (Unplugging short circuited) Parity: 8E1 (even parity)  
Then the used configuration in the project is:
A = 1   B = 1   C = 1   D = 0   E = 0

<table>
<thead>
<tr>
<th>PIN</th>
<th>SIGNAL NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GND</td>
<td>Ground</td>
</tr>
<tr>
<td>2</td>
<td>VCC</td>
<td>Power supply DC</td>
</tr>
<tr>
<td>3</td>
<td>RxD/TTL</td>
<td>Serial data input to the transceiver</td>
</tr>
<tr>
<td>4</td>
<td>TxD/TTL</td>
<td>Transmitted data out of the transceiver</td>
</tr>
<tr>
<td>5</td>
<td>SGND</td>
<td>Signal</td>
</tr>
<tr>
<td>6</td>
<td>A(TxD)</td>
<td>TxD of RS-232</td>
</tr>
<tr>
<td>7</td>
<td>B(RxD)</td>
<td>RxD of RS-232</td>
</tr>
<tr>
<td>8</td>
<td>SLEEP</td>
<td>Sleep control (input)</td>
</tr>
<tr>
<td>9</td>
<td>RESET</td>
<td>Reset signal (input)</td>
</tr>
</tbody>
</table>

Figure 4 HAC UM96 Pin Descriptions

Temperature Sensor (DS18B20)
The DS18B20 digital thermometer shown in figure 5 provides 9-bit to 12-bit Celsius temperature measurements. It communicates over a 1-wire bus that by definition requires one data line to
communicate with the HCS12 processor. Each DS18B20 has a unique 64-bit serial code, which allows multiple DS18B20s to function on the same one wire-1 data bus\[7\].

The 1-Wire bus system uses a single bus master to control one or more slave devices. The DS18B20 is always a slave. When there is only one slave on the bus, the system is referred to as a “single-drop” system; the system is “multi drop” if there are multiple slaves on the bus. All data and commands are transmitted least significant bit first over the 1-Wire bus. 1-Wire bus system is broken down into three parts: hardware configuration, transaction sequence, and 1-Wire signaling (signal types and timing). Hardware Configuration can be defined as the 1-Wire bus has by definition only a single data line. Each device (master or slave) interfaces to the data line via an open-drain or 3-state port. This allows each device to “release” the data line when the device is not transmitting data so the bus is available for use by another device. Therefore, one master microprocessor can control many DS18B20s at different location. This feature is very useful in HVAC environmental temperature controls or any other temperature monitoring control systems\[2\].

The transaction sequence for accessing the DS18B20 is as follows:
Step1. Initialization  
Step2. ROM Command (followed by any required data exchange)  
Step3. DS18B20 Function Command (followed by any required data exchange)  

It is very important to follow this sequence every time the DS18B20 is accessed, as the DS18B20 will not respond if any steps in the sequence are missing or out of order. Exceptions to this rule are the Search ROM [F0h] and Alarm Search [ECh] commands. After issuing either of these ROM commands, the master must return to Step 1 in the sequence.
All transactions on the 1-Wire bus begin with an initialization sequence. The initialization sequence consists of a reset pulse transmitted by the bus master followed by presence pulse(s) transmitted by the slave(s). The presence pulse lets the bus master know that slave devices (such as the DS18B20) are on the bus and are ready to operate.

**HAC-UM96 interface with HCS12**

Proper connections need to be done as shown in figure 6 so that communication between master and slave board takes place. Two HCS12 boards are named as slave boards 1 and slave board 2 respectively. One HCS12 board is named as master board. The slave board will read the temperature and send it to the master board wirelessly through the help of RF module.

Figure 6 HAC-UM96 interface with HCS12

Pins 3 and 4 will not be connected to the HCS12 microcontroller and the connection remains open. Make sure Pins 1, 5 and 8 are properly grounded. Pin 6 and Pin 7 i.e. Transmitter and
Receiver of HAC-UM96 will be connected to the Receiver and Transmitter of HCS12 board respectively.

**Temperature Sensor interface with HCS12**

Temperature sensor interface with HCS12 is shown in figure 7. Pin 1 of temperature sensor is properly grounded. Pin 2 i.e. Data Input/output pin is connected to PE4 of HCS12. Pin 3 is connected to voltage supply of 5v from HCS12 board.

![Temperature Sensor Interface](image)

**Figure 7 Temperature Sensor Interface**

**Operation and Conclusions**

In conclusion, when the board is powered on and a reset is pressed on the Slave Board 1, the temperature sensor connected to the HCS12 reads the room temperature. Similarly when the board is powered on and a reset is pressed on the Slave Board 2, the temperature sensor connected to the HCS12 reads the room temperature. Now the Master board is powered on and a reset is pressed. The UM-96 connected to the master board will try to make a contact with slave board1 and 2 respectively requesting the HAC UM96 connected to the slave boards to transmit the data i.e. temperature to the master board. The master board will read the temperatures sent by both the boards and display it on the LCD of the microcontroller. If the temperature of the particular zone increases above certain defined range, an alert will be there through the help of a speaker. This project can be implemented with higher range of modem and expanding the current network of 2 zones to a network of several zones so that master board can read temperature from different locations.

**Bibliography**


Biography

Reza Raeisi, PhD
Dr. Raeisi is an Associate Professor and graduate program coordinator in the Department of Electrical and Computer Engineering at California State University, Fresno. His research interests include Integrated Circuits, VLSI-CAD, and Embedded Systems Design. He is an experimentalist and enjoys hands-on working in the area of FPGA based digital design synthesis and system level modeling using HDL, and application of embedded microcontroller hardware and software as they related to education and laboratory environments.

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Mr. Deepak Anand received a Bachelor’s degree in Electronics and Communication from Uttar Pradesh Technical University in India in 2006. He also received a Master’s degree in Electrical Engineering from California State University Fresno in 2008. His research interests include nanotechnology, embedded system, and control systems.
The Capstone Design Experience in the Mechanical Engineering Department at California State University, Fullerton

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Abstract

The terminal learning experience in the mechanical engineering program at California State University, Fullerton is the series of two design classes: ME 414 and ME 419 taught respectively in the Fall and Spring semesters. These two courses have the goal of immersing the students in the real-life engineering problems where they are engaged in systematic application of the principles of design and solving open-ended problems for specific situations and/or needs and in utilizing knowledge acquired during their studies at the University. Design is about testing ideas, failures and successes and solving problems as these appear during the semester. Decisions have to be made at each step of the process, compromises must be reached among the team members, optimization of components is done and ultimately the project must be fabricated, tested and it must perform as stipulated, that is the requirement that the department has imposed on each and every design project. The principal objective of this sequence of courses is for the students to develop an understanding of the design process as it applies to a serious mechanical engineering project. Students must to be able to select standard off-the-shelf components as well as design non-standard mechanical sub-systems. One of the key features of these two courses is the creative utilization of contemporary software packages i.e. Pro-E, Fluent, Ansys, Solid Works as well as MathCad, MatLab, AutoCad and Project Management software. Simulation is readily utilized and the students readily appreciate ability to virtually analyze a real system rather than engage in costly sequence of physical prototypes designed iteratively by intuition and/or trial-and-error prior to building a physical prototype. Strict requirements are maintained in developing the RFP and subsequently the proposal for the projects, maintaining the documentation of the progress, adherence to the Gantt chart and communications with the vendors and/or fabricators. Cost issues are carefully evaluated and teams are mandated to stay within the allocations given either by the instructors or industrial sponsors. Project teams are strongly encouraged to seek additional funding from sources within and without the University, i.e. from chapters of professional organizations (ASME, SAE, SAMPE), Orange County Engineering Council - the umbrella organization of all engineering societies within Orange county and from major industrial corporations such as Boeing, Fluor, Parsons, General Dynamics, Lockheed-Martin, Hughes etc. The projects given to the teams vary so as to meet their individual interests ranging from biomedical projects, automotive (Mini Baja, Drift Car, Formula One), avionics, renewable energy, equipment for the handicapped... Teams are carefully created with the intentions of balancing students’ talents and skills as well as their desires to work with their friends. The penultimate results are a working prototype and a portfolio detailing all elements of each of
the design projects. The Power Point or similar presentations which take place at the end of the semester in front of Design Juries is the climactic event of the courses where the defenses of the projects are conducted and which is a significant component of the grades given to each design team member for their performance and contributions to the project.

**Introduction**

Contemporary work environments request/mandate that engineers be able to participate in work on diverse projects and make their contributions to the effort. Therefore it is incumbent on the Universities teaching design to provide the requisite learning experiences preparing the future engineers to hit the ground running and deliver what is expected of them. The Capstone Design experience at California State University, Fullerton has as its goal to provide this experience\(^2\). The theme of the experience is set jointly by the students and faculty during the beginning of the first class. Interests of the students are explored and evaluated and ideas for projects requested. Subsequently, additional ideas are brought for consideration by the teaching faculty. Usually, these are projects obtained from local industry or from different parts of the University. The discussions about which projects to select are an integral part of the course as the financing of the projects with respect to the ability of the department to fund these is of course quite limited. The current financial circumstances in the university and the inability of the department to provide any funding whatsoever curtails the ability of engaging in more ambitious and more complex projects. That placed tremendous pressures on the instructors of the course to obtain the requisite resources for the conduct of the classes. Prior to the day the projects were actually assigned to the students another serious aspect which had to be considered was that not all students came with identical background, but with a wide array of talents, manual and computer skills, experiences, cultural backgrounds etc so that creating teams that could and would function harmoniously presents a rather complex task. An additional aspect to the original purpose of the capstone courses was satisfaction of the ABET requirements regarding design activities, specifically with “an ability to design a system, component, or process to meet desired needs” as well as to possess “an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice”. This was achieved through ongoing discussions and progress briefings with each of the teams as well as confirmed by the assessments of the design juries and the mechanical engineering advisory board members providing inputs to the student teams.

**Conduct of the Capstone Design Courses**

Matching the students’ interests turned out to be a harder task than originally thought to be. Every student had visions of working in their own field of interest which is unlikely to take place in most work environments. Yet, the authors know from long standing experiences that if the students are energized with the assignments close to their hearts they would invest the time necessary for the project and deliver better products. The majority of the students prefers and enjoy working on projects which involve competitions, i.e. Mini Baja, Human Power Vehicles and Human Powered Submarine, SAE Air Cargo, Drift Car, SAE Formula One car, ASME Super Mileage vehicle…The pace of these projects is dictated by the deadlines which each of the competition entails and are excellent examples of the pace
encountered in industrial settings. While these projects entail excellent engineering challenges they are also good for the reputation of the program as well as for building and maintaining connections with the alumni. Yet, one of the authors of this paper prefers projects which have a more humanistic nature and are for the benefit of the society such as designing equipment for the handicapped, items that are usable in Kinesiology department of our university like The Stability Platform, New Surgical Devices, equipment that aids rehabilitation of the patient after surgery, design for the elderly and for eclectic projects for the local industry such as the aircraft winch, camera for inspection of various structures, re-design of wheelchairs, robotic painting devices… There are several additional interesting aspects of conducting the capstone design courses which include discussions of selected case studies from the ASEE Case Studies Committee Library which is currently at Rose-Hulman Institute of Technology in Terre Haute, Indiana, analysis of some more prominent failures encountered in the engineering practice along with demonstration of some of the movies illustrating these. Safety concerns were emphasized during the conduct of both of the courses with numerous illustrations as to how failures occurred and how the prevention of these could have been achieved. Human Factors and Safety concepts were discussed at length and examples of product liability cases brought to the students’ attention in order to sensitize them to that paramount cannon of the ASME Engineering Codes of Ethics which is that “Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties” and that “Engineers shall recognized that the lives, safety, health and welfare of the general public are dependent upon engineering judgments, decisions and practices ...”. Different hazards in design must be recognized and dealt with in the optimal way i.e. kinematic, energy, electrical, chemical, material, environmental, ergonomic ones etc. Also, it is important to recognize potential for misuse or abuse of products, particularly with regard to maintenance aspects. Ethical issues of the engineering practice are discussed with regard to the well known engineering cases. Maintenance of weekly logbooks of progress, or lack thereof, was an integral part of the requirements for the course which had to be met. These were inspected by the course instructors and signed off on the weekly basis. The contents of these logbooks had to be scanned and presented with the final design project report along with the specifications of purchased off-the-shelf items. Fabrication of projects was done mostly at the facilities within the University with able assistance of our machine shop. Students have previously learned to utilize most of the machine tools within the shop and were doing a good amount of the machining themselves. Some of the fabrication was outsourced when necessary. The importance of avoiding obsolescence is being impressed throughout of the courses as is the need to pursue learning throughout one’s career.

**Funding of the projects**

The California fiscal crises notwithstanding, the funds for the projects have for years originated as a result of the instructors’ entrepreneurial efforts and activities. The bulk of the funds have been secured by submitting proposals to the CSUF student government’s IRA – Instructionally Related Activities fund which has enthusiastically supported the project activities. The fund’s resources hail from students’ fees. Proposals for the funding of the projects undergo a rigorous scrutiny of a large committee consisting of students, faculty and administrators. The committee then allocates the funds to those projects it deems to be
worthwhile. The support of the different project activities is a long standing tradition at the university and has contributed to numerous ambitious and sophisticated projects across the spectrum of different disciplines. Some mechanical engineering projects have been funded by the local industry for a variety of reasons: the projects are of the type that are not of an urgent nature and are on the proverbial “back burner” so that the time for completion is not of essence, the projects can be done over the two semester period which is the duration of the two capstone courses, the only costs of the projects are the components and fabrication as the students’ and faculty labor come free. The industry funded projects serve as an excellent recruiting tool for new engineers where the company engineers interact with our students and can evaluate their prospective contribution and subsequently decide if they should be hired upon graduation. Also, it is a good public policy for companies to maintain active relationship with the biggest local University in Orange County. Interestingly enough, some projects were directly and completely funded by the students or their families. The rules for these rare projects were clearly laid out: if any funds whatsoever utilized in the projects come from the University the project remains property of the University. If the project is completely funded externally it belongs to the source of funding. However, the owners of the project must
\textit{a priori} agree in writing to let the University be able to loan the prototype for special occasions such as Open House Tours, ABET visits, Job Fairs etc with the appropriate time notice. Interesting situations arise from time to time with respect to the intellectual property associated with the projects as some have potential to generate income once a patent is issued. These have been handled on a case by case basis. In some circumstances the University has yielded the patent rights to the sponsor of the project while in other cases a sharing of future income has been negotiated. Pursuit of patent rights is an expensive process and has been in most cases left to the sponsor of the project yielding a larger share of potential future profits. Instructors have waived their rights to the benefits but retained the rights to be named on the patents, if granted. The intent of the department has from the inception of the projects been that the students are not expected to contribute to funding of any of the projects. In view of the cataclysmic changes taking place at this very time this approach may regrettably have to be changed? The projects originating from industry have been the result of the active Departmental Advisory Board as well as a result of the good relationship with the alumni of the program who cherished opportunities to be engaged and help their Alma Mater. During the conduct of the courses the students were encouraged and guided to seek support for their projects on their own. They were taught how to write granting proposals and seek out sponsors for their efforts. The support requested was in form of cash, components, discount on purchases, help with travel arrangements etc. The sponsors would, in turn, obtain favorable publicity as their logos would be posted on the project. Additionally, the students were encouraged to give presentations to chapters of the professional engineering societies and seek their support as well. The learning curve on fund raising was a steep one as very few students, if any, did ever anything similar but they rose to the occasion and were successful in their efforts.

\textbf{Use of Modern Design Tools}

It is difficult to envision contemporary design without a comprehensive utilization of modern computational tools. Student teams were provided with numerous software
packages acquired by either the university or the mechanical engineering department such as AutoCAD, Fluent, MathCad, MathLab, Project Management software, Solid Works, ProE, Cosmos, Ansys etc. Additionally, most projects required usage of specialized software which was purchased, if affordable, to support the design activities at the appropriate technical level of sophistication. The Air Cargo project utilized NASA Airfoil design software and Simufoil, the Mini Baja utilized software for modeling of the suspension of the vehicle and shock and vibration behavior of the frame. Every effort is made during the conduct of this (and other) courses that the word processing, spreadsheets, Cad/Drafting, project management, internet communications and web browsing are in the inventory of the skills of our graduates. The car related projects represent ideal settings to learn object related programming as software allows modeling of various physical components of the car: its engine, transmission, differential, tires, steer mechanism, suspension etc. Students were able to design a car within the constraints provided. Many of the other projects also lend themselves to computational modeling of components and systems.

Communication Skills

Engineers are to be employed in a wide variety of business functions, for example: Technical marketing, product research and design, plant operations, fabrication and their ability to successfully perform in these functions demands that they be good communicators both in writing and in oral presentations. During the capstone design courses teams were mandated to regularly deliver progress reports by using Power Point presentations. The resistance to this requirement was palpable, particularly from students with the foreign background, but after some time passed the students were able to deliver good briefings and to choreograph their presentations. The instructors encouraged questions and answers engagements which resulted in interesting discussions involving the entire student body of the class. Ultimately, at the end of each semester, the teams gave final presentations to the instructors and the design jury specially constituted for this purpose. The members of the design jury challenged the teams with the questions related to the alternatives considered when doing the arriving to a particular decision. Another interesting aspect of communication was the interaction with suppliers. The contact had to be made with different manufacturers and information was sought regarding to specific components performance as well as the cost of these. Students had to research the companies producing the said components, obtain the technical specifications and data and ultimately select the optimum one for their application with the appropriate cost for it. Members of the Mechanical Engineering Advisory Board interacted with the teams on several occasions and provided much of valued constructive critiques. Members of the Board have also reviewed the final reports of the teams for both semesters and offered their comments and suggestions for improvements. Efforts were made to ascertain the proper level of literacy in the reports with respect to grammar, syntax, spelling, vocabulary to make them achieve the desired high standard. Since a large number of students were foreign born this required a special effort on behalf of the instructors.

Information Gathering

Proceedings of the 2009 American Society for Engineering Education Pacific Southwest Regional Conference
Every team had to evaluate the current state of the art of the know-how of the project it was working on. That required extensive information gathering both by conventional means in library searches and by contemporary methods via search engines, patent searches, visits to the industry and interviews with engineers knowledgeable with the product. Of immense help were the briefings of the reference librarians of the California State University, Fullerton. They met with each team separately and helped them identify the sources which would be helpful in their work; the published works of the persons engaged in the like efforts and have obtained, via interlibrary loans, documents pertinent to the individual searches. Their contributions to the effort cannot be adequately recognized as their knowledge and skills in the searches significantly abbreviated the students’ efforts and lead them directly to the most appropriate sources and taught them to avail themselves of these powerful contemporary tools.

Conclusions:

Universities and educators are working together to identify requisite engineering skills and abilities for the entry level engineers and to facilitate their transition from the graduating senior to an engineering professional who carries his or her own weight in the industry. There is no better opportunity to do so than in the capstone design projects courses such as the ones discussed in this paper. The constantly evolving industrial practice demands that a constant vigil and attention be given to determining which evolving skills are to be required of current graduates and where and when are these to be introduced and practiced. The successful projects in the ME 414 and ME 419 courses proved to be valuable to the graduates of the CSUF mechanical engineering program as their portfolios of the final design projects were convincing documents about their competency in the profession, written and oral communication skills, leadership abilities and indeed most helpful during the interview process for steady employment.

Appendix:

Examples of projects accomplished in the ME 414 and ME 419 Capstone Design courses at CSU Fullerton

- SAE Mini Baja
- Drift Car
- SAE Formula One Vehicle
- Human Powered Vehicle
- Human Powered Submarine
- ASME Super Mileage Vehicle
- SAE Air Cargo Plane Design
- Bowling Machine for Handicapped Persons
- Frisbee Thrower for Handicapped Persons
- Landsailer Design
- Rehabilitation Device for People after Hand/Finger Surgery
- Tool to Assist Surgeon during Surgery and Reduce Hemorrhage
- Ankle Testing Device for Kinesiology
- Balance Response Platform for Stability Assessment for Kinesiology
- Rehabilitation Device after Knee Surgery
Lift for Placing and Extracting of a Handicapped Person to the Pool
Robotic Painting Device
Conversion of an Internal Combustion Automobile into an Electric Vehicle
Hovercraft Vehicle Design
Platform for Mounting Inspection Cameras
Thermal Management Unit
Solar Hot Dog Cooker
Automatic Shish Kebab Machine
Rickshaw Design
Sterling Engine
Movable Mirror Focusing Solar Collector

References:

5. ASME International Code of Ethics

Biographies

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Agile Problem Driven Teaching in Engineering, Science and Technology

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ABSTRACT:

In problem driven teaching, all major teaching activities are driven by a problem or a set of problems. Some typical problem solutions are demonstrated by the instructor. Problems could be based on real world or realistic or abstract situations. Recent research suggests that abstract problems may have some advantages over others. This paper demonstrates how course learning outcomes are adequately handled in agile problem driven teaching in Engineering, Science and Technology courses for effective interactions.

Problem driven teaching is not the same as Problem Based Learning (PBL). Students as well as educators enjoy PBL. With PBL, learners are usually organized into groups, and one or more problems are given to each group for solving the problems under the supervision of the instructors. Although PBL is highly successful in certain environments, it is not necessarily appropriate for all learners and/or all topics, since the teaching methods may not be dynamically adjusted modified on the basis of different challenges faced by different learners for different topics. Adjusting teaching methods based on learner feedbacks may be appropriate in multi-model, multi-strategy learning environments. Agility in teaching/learning and grading helps to overcome the different challenges faced by different learners for different topics. Our discussion of agile problem driven agile teaching considers all instructional strategies including lectures, transformations, experimentations, problem solving, analogical, case-based and mathematical reasoning for affective learning utilizing tools and technologies in an innovative way. Teaching is unlike any other job; Aan effective teacher must takes complete responsibility for student's learning and reasonable grades specification. Agile problem driven teaching may be the right approach for solving some of the most crucial problems in engineering education.

1. INTRODUCTION

According to the 2005 report of the National Academies, “Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future,” the USA is losing its long-standing global lead in science, math and engineering education (The National Academies, 2005). “Recent test results show that U.S. 10th-graders ranked just 17th in science among peers from 30 nations, while in math they placed in the bottom five” (Wallis, 2008). There is enough indication that this educational trend is temporally
coupled with a closely following severe economic down turn. Clearly, prolongation of this trend is a danger to the U.S. economy and the U.S. standard of living. We live in a rapidly changing world, with a global job market, global educational competition, a globally integrated economy, escalating energy problems, mounting trade imbalances and an unprecedented financial crisis. The new U.S. generation of the USA needs to have modern educational advantage in order to compete in the global job market and solve exigent problems. Well educated engineers, technologists and scientists are in demand. In order to build a robust economy with sustainable growth, educated problem solvers are needed. However, schools and colleges are not succeeding in producing innovative problem solvers. Many different teaching strategies that have been tried show important improvements in student learning in different settings (Borman, 2005). However, significant nationwide improvements have not been achieved despite these isolated demonstrations of some successful cases.

Problem Driven Teaching is closely related to -Based Teaching is frequently associated with Problem-Based Learning (PBL) which is the educational process by which problem solving activities and the instructor’s guidance provides educational materials and guidance that facilitate learning. PBL It is the pathway by which students “learn how to learn”. It challenges students to think critically, be pro-active, analyze problems, and find and use appropriate learning resources. (Queens 2009). In Problem Driven Teaching (PDT), all major teaching activities are driven by a problem or a set of problems. Some typical problem solutions are demonstrated by the instructor and students practice problem solving among other activities in order to master the learning outcomes. Problems could be real world or realistic or abstract. Recent research suggests that abstract problems have some advantages over others (Kaminski, Sloutsky, Heckler, 2008). However, unlike PDL, an important aspect of PDT is that instructor plays an active role in teaching activities.

Problem Driven Teaching (PDT) is not the same as Problem Based Learning (PBL). In a PBL environment, students are usually divided into teams to work on problems. In this model the problems are expected to drive the learning activities, a common practice in medical science, particularly in psychiatry (Adamowski, Frydecka, & Kiejna, 2007). In this strategy the instruction of the topic is organized around problem solving tasks. Some of these tasks are problem analysis followed by relevant information gathering; students may then try to identifying some possible solutions and provide pros and cons of each proposed solution. This strategy gives students abundant opportunities to think critically, communicate with their team members, present arguments as well as counter arguments, transfer knowledge to new situations, and develop creative problem solving skills. A key element of this approach is that all the problems are designed in such a way that students must gain new knowledge before they can solve the problem. One of the authors (A Datta) will be testing this approach for teaching cyberinfrastructure (CI) to the biology students under CIBRED (CI-TEAM Implementation for Biological Researchers, Educators, and Developers), an NSF funded project. Teaching engineering concept to biologist and other non-engineering students is always challenging (Datta, et al., 2009). Nevertheless, the impact of CI in education is such that the Office of Cyberinfrastructure (OCI) at the National Science Foundation has established a rich source of educational and research material.
materials through TeraGrid (TeraGrid, 2007) to meet the 21st Century's demand for scientific talent. Materials are freely available through CI/TeraGrid (Kay, et. al., 2008). Additionally, OCI put forth the CI-TEAM (Cyberinfrastructure Training, Education, Advancement, and Mentoring for Our 21st Century Workforce) program to aid education initiatives directed toward this new workforce. CIBRED is one of the funded collaborative projects (awarded to O. Crasta of VBI with A. Datta as a collaborator) of this OCI initiative. Courses are now being developed in a collaborative way using multidisciplinary approach integrating scientific and technology information from a variety of disciplines. The focus is to teach students from diverse disciplines for learning some essential concepts on computer technology in the context of application of cyberinfrastructure. These courses developed for K13 & K14 levels will be offered in an innovative classroom setting for hands-on experimental learning with a focus on solving a scientific problem as a team. However, such an approach will be effective if the instructor follows the agile teaching technique to facilitate forming the students group working on a specific scientific problem. Often time, problems are complex and may not even be well defined. The new knowledge is acquired as students try to work through the problem. The role of the instructors in this environment is mainly the facilitator and the guiding mentor. Students are given more responsibility for their own learning and are engaged in active or discovery learning in the sense that students discover and work with content that they determined to be necessary to solve the problem. It is believed that by working thorough the problems, students are better able to internalize the problem and understand the underlying concepts and fundamental relationships needed to solve the problem. In a traditional setting, instructors tend to simply provide students with facts, this is known as teacher-oriented instruction; and many students may not be receptive to or grasp the new concepts. As a result they either tune off or never develop a deep understating of the materials and simply imitate mechanical operations and the essential analysis and arguments necessary to solve the problem. One common criticism of the PBL method is that students may not recognize what might be important for them to learn, so the facilitator must be extra careful to assess each student’s prior knowledge. Another criticism is that instructors cannot cover as much material as the traditional method. Furthermore the method is hard to implement and moreover, there are different definition and interpretation of the strategy and the manner of its implementation within instruction appears to be ad hoc. PBL method requires a lot of planning and requires extensive work for the instructor.

In this paper we propose a new variation to PBL active learning approach where the role of the instructor is more than being just a facilitator. We introduce the model of Agile Problem Driven Teaching (APDT) in which the instructor’s role more closely approaches the traditional instructor approach. In APDT, however, the instructor’s presentation is more dynamic and can easily digress to cover a variety of “relevant” topics according to inquiries received from students. We call this approach an Agile Problem Driven Teaching (APDT). Similar to its PBL counterpart, the class is given a complex problem to solve. However, unlike the PBL the role of the instructor in this approach is elevated to periodic coaching/lecturing in order to accelerate the PBL strategy. In particular the instructor plays a key role contextualizing the problem and actively participating in the research, analysis, and information gathering component of the PBL. The instructor

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becomes a facilitator once the initial body of knowledge to solve the problem is gathered. This gives students an opportunity to put together the final solution. In the APDT method the open problem along with student inquiries and the collective information gathering process derives the lecture, and this is where the agility in instruction becomes apparent and critical. The instructor must have extensive knowledge of the subject to efficiently process information and resolve student’s questions and further suggest new directions for information gathering. In this method the new knowledge is shared among all teams in a form of a short presentation by the instructor. This provides the instructor with an opportunity to further clarify student misunderstandings and misinterpretation associated with the problem and the newly acquired information.

Use of technology can further simplify the APDT implementation and enhance student experience. In particular, in one scenario, students and the instructor each will have Tablet PCs with collaborative, interactive teaching tool such as Dyknow vision in a networked environment. In this, often wireless, networked environment, the Instructor’s display is broadcasts to student’s machines allowing students to synchronously follow instructor’s lectures and add notes to the lecture with ink pen. The instructor can also permit students to lead class from their own machine. This connectivity clearly facilitates a powerful medium for students to collaborate and share as they search for new knowledge to solve the problem. Among useful features of Dyknow is the panel submission. Panel submission is most useful for APDT, in this mode each team can, anonymously, submit their findings and request comments from the instructor. The instructor can quickly scan through all student submissions and select one or more panels to share with the rest of the class. It is through this sharing that the instructor can clarify misunderstandings, make additional comments or presentations, or provide new directions for search. The instructor can also opt to privately give comments to student submissions. Many educators have reported increase in student participation when Tablet PCs are used in the class. Panel submission and the follow up discussions often clarify many student misunderstands; the instructor can utilize the panel submissions to point out common errors and misinterpretations, or focus on the new knowledge reported by students to point out its relevance to the problem.

Adjusting teaching methods based on learner feedbacks may be appropriate in multi-cultural learning environments. Agility in teaching/learning and grading helps to overcome the different challenges faced by different learners for different topics. According to Glickman "Effective teaching is not a set of generic practices, but instead is a set of context-driven decisions about teaching. Effective teachers do not use the same set of practices for every lesson . . . Instead, what effective teachers do is constantly reflect about their work, observe whether students are learning or not, and, then adjust their practice accordingly (Glickman 1991). Our ability to teach is enhanced with our agility to adjust. In education, the same size does not fit all.

Agility is the basis of APDT and APDT, consequently, it may combine a variety of teaching strategies. In addition to PBL, many other teaching and /learning methods can be employed in teaching including the following:, lecture (Cashing 1990);, class discussion, brain storming, (instructional methods 2009);, technology-based learning (Trondsen, 1998);, game-based learning (Prensky, 2004; Van, 2008);, community-based learning
Owens & Wang, 2008); work-based learning (Bailey 2003; Cunningham, Dawes & Bennett, 2004); inquiry-based learning (Eick & Reed, 2002; Educational Broadcasting Corporation, 2008); project-based learning (Helic, Maurer, & Scerbakov, 2004; The George Lucas Educational Foundation, 2008); team-based learning (Michaelsen, et al., 2008); web-based Learning (Lee & Baylor 2006; O'Neil & Perez 2006); and participatory learning (Barab, Hay, Barnett, & Squire, 2001). There is no conflict between these methods and APDT since it can adopt these methods if needed. An agile PDT method can combine with any of the strategies because of its agility.

2. PROBLEM DRIVEN TEACHING IN MATH FOUNDATIONS

At National University, the APDT method was applied in a graduate course on mathematical foundations of computer science (National University course number CSC 610). Cohen (1997) was used as the textbook for this course. Lectures, class discussions, brainstorming and quizzes were used regularly following the textbook. However, one main problem drove all these activities. In the first meeting for this course, each student was given a variant of the following problem.

Class-Problem: Build the most powerful computing machine that you can think of. Your machine should be able to process complex languages such as \( L_{11} = \{a^n d^n y^n : \text{where } n > 0 \} \). Demonstrate that a string like ‘aadcdy’ would be accepted by the machine. You need to build the machine by defining its elements mathematically. You are not required to deliver the machine with hardware components. If you do not use standard notations provided in the textbook or discussed in the class then you need to explain your notations.

It is known that Finite State Machines or Finite Automata can accept regular expressions. So, any string from the regular expression \( b^*aba*b \) would be accepted by the following Non-deterministic Finite Automaton (Figure 1).

![Figure 1. A Non-deterministic Finite Automaton for b*aba*b](image-url)
However, Non-deterministic Finite Automata cannot process a language like $L_{11}$, mentioned above, which requires a more powerful machine. You should be able to build such a machine. Explain how your machine will accept strings from $L_{11}$.

**PART 2:**
A Turning Machine has a finite set of states with one START state and some (may be none) HALT states. We always mark the START state with 1 and the HALT state with 2 (when there is only one HALT state).

![Diagram of Turing Machine](image)

The Turing Machine given above accepts the language: $\{ b^*a b^*a \}$. When an input is given it is processed by the transitions as the Turing Machine goes from state to state starting from the start state. The input is accepted by reaching the HALT state. If the HALT state and its incoming transition are destroyed then no input is accepted. The Turing Machine of Figure 2 would look like the machine given below after the destruction of the HALT state and its incoming transition.
Figure 3. The Turing Machine of Figure 21 after the HALT state and its incoming transition are destroyed.

If the input is: aba, then the machine will start in the START state and reach state 4 after going through the loop of state 3. However, the input is not accepted.

You are asked to complete the following three tasks:

1) In the first step, destroy the HALT state(s) and their incoming transitions of your machine of the assigned problem (of PART_1) and examine the consequences.
2) In the second step, destroy the START state and the associated transitions of your machine (in addition to the destructions mentioned in step 1) and examine the consequences.
3) In the third step, reconstruct the machine so that it is distinct from the original machine of PART_1 (may have one or more additional states and/or transitions) and still process the same language (end of the Class-Problem).

The above problem was given out at in the first meeting and the students started working on the problem and all teaching activities were the teaching of all aspects of the math foundation is related to this problem. Finite Automata, Pushdown Automata, Linear Bounded Automata, Turing Machines, and Post Machines and the related sets accepted by these machines are taught with the goal of solving the above problem. The class
started with the Finite Automata which could process regular expressions but would not be adequate for Context-Free languages. Pushdown Automata were then introduced in order to process Context-Free languages as well as regular expressions. The machines were built for dealing with increasingly complex sets. Finally, the problem was solved by building a Turing Machine for \( L_{11} \). The students then experimented with breaking some parts of the machine and examining the consequences and then performing the repair work on the machine following the Part II of the problem. The teaching of the entire course was driven by the set of problems presented including the main problem mentioned above. Effectiveness of the teaching method was not measured scientifically although students evaluated the course according to the usual National University evaluation method which indicated significant improvements over earlier offerings of the same course.

The course learning outcomes for this course are given as follows. Upon successful completion of this course, students will be able to:

* Construct a model of computation for a given specification.
* Construct a Turing Machine for a given computational problem.
* Develop a program implementing the model of computation.
* Prove that regular expressions are equivalent to Finite State Machines.
* Prove that complement of a regular language is regular.
* Prove that a given language is Context-Free.
* Construct a Push Down Automaton for a given computational problem.

The first two learning outcomes are directly achieved through the class problem described above. Other learning outcomes are discussed when attempts are made to build machines of different types in the process of finding increasingly more powerful machines.

3. PROBLEM DRIVEN TEACHING IN DATABASES

Various approaches to the teaching of computer science courses are currently under use and consideration. This author (M. Wyne) has attempted a few teaching strategies that seem to make a difference in student understanding of the subject matter. To start with, I have revised my handouts to include not only the important materials for in-class discussion, but also to include study questions and practice problems in the handouts. The questions in the handout serve to challenge their thinking processes when it is time for them to study. They also help to generate more in-class discussion. Once in a while, I will discuss structure-activity relationships by asking students for their input instead of providing all of the facts for them. If a wrong answer is suggested, I usually follow up with another question to allow the students to see why it is not a good answer. I fully realize that by involving the students in lectures in this way, I may not be able to cover as much material as I would like, but I have never felt that I was not in control of my lectures. I have found that not only do the students learn database design better, but they also come to enjoy the subject more, and have often come in to discuss their own experiences in database design with me on an informal basis. Furthermore, at the end of each major topic, I usually discuss one or two practice problems from previous exams,
again with active participation from the students as a way to show them how to solve the problems. Additionally in my courses, I do encourage my students to come and discuss their solutions with me. In doing so, I am able to see their approach to learning and also which concepts are difficult for them to grasp. This allows me to think of different approaches to convey these concepts.

I have taught required introductory database design course to computer science students. I was interested in incorporating some of the PDT problem-based teaching techniques. The PDT problem-driven teaching approach I use is a new concept in teaching of introductory Database courses. In this approach a problem is introduced and emphasized to students in order to make the study of database design more relevant to what student may experience in their practical life after graduation. For the past few years, what I came up with was a bit of “How to design a database for a company”. The requirements of the company database are also provided as “The Company is organized into DEPARTMENTs. Each department has a name, number and an employee who manages the department. We keep track of the start date of the department manager. Each department controls a number of PROJECTs. Each project has a name, number and is located at a single location. For each EMPLOYEE’s we store, Social security number, address, salary, sex, and birth-date, number of dependents. For dependents. For each dependent, we keep track of their name, sex, birth-date, and relationship to employee. The number of hours per week that an employee currently works on each project is recorded. The direct supervisor of each employee is also important. We also know that each employee works for one department but may work on several projects”. These initial set of requirements gives students a good start and allow them to guess and work out other details.

The design of the problems that are used in PDT problem-driven teaching plays an important part in achieving the intended learning objectives set by the faculty teaching a course. To a large extent, the learning objectives set for the course determine their learning activities and form the framework for the direction of teaching methodology. I use problem driven teaching PDT approach to address four challenges: inadequate time to cover important material using only a traditional lecture format; enhance student motivation to study the material on a daily basis rather than just the night before an examination; increase student comprehension of the material, as well as increase student awareness of the level of comprehension required for satisfactory performance on examinations; and the necessity for the students to see the "whole picture" of the design before it is covered in class, as a mechanism for teaching students how to use logical thinking in learning the concepts presented in the course. During the first class with the students I present a problem, design a database for a company. Each lecture starts by introducing and reviewing the main concepts and steps required to develop an efficient database design. Design strategies commonly used are presented and the effects of any of the design features on their overall database design are discussed. The students are asked to recognize the effects of a specific design decisions on the overall system operation. This is further emphasized by practical situations that are presented in the lecture. Consequently, they are expected to apply this information to a question on the examination. In this approach, I will ask several probing questions which are designed to stimulate the students' understanding regarding design decisions, and possible side effects.
4. AGILE PROBLEM DRIVEN TEACHING IN INFORMATION TECHNOLOGY (IT)

4.1 APDT in IT Focuses on Real-world Problems

Information Technology (IT) emphasizes synergistic solutions between technology, people and processes to successfully resolve enterprise computer problems. In the IT Management (ITM) program at National University, students learn that people, namely the client, drive the development process. IT professionals, with their knowledge, skills and set of technology tools attempt to meet the requirements specified by the client. In almost every development instance, the client’s perception of the desired product evolves. The initial functional specification frequently defines a problem that may not have a solution as specified. Consequently, the engineering IT development team may have to redefine the problem in order to deliver a workable solution. In order to meet deadlines, frequently, the problem may be subdivided into modular components assigned to separate development teams. This is where APDT better prepares IT professionals to handle such common challenges encountered in the workplace.

Similarly to PBL, APDT as used in ITM focuses on real-world problems. Additionally, “agility” features are introduced to more closely simulate the real-world workplace that students will encounter. Agile components introduced are a) including multi-faceted problems that are subdivided into multiple team interaction and coordination, b) adjusting the defined problem to team-member skills, and c) allowing team-members to discover alternate solutions and “work-arounds” when barriers are encountered while discovering the solution to a problem. Redefinition of the problem in order to achieve a solution is frequently required in ITM. Introducing students to this realistic occurrence by employing the APDT method in their instruction better prepares them for the workplace.

Where PBL is based on a defined problem with usually one solution, APDT is based on the premise that agility, and creativity are required to redefine the problem in order to achieve a successful solution.

4.2 Information Security Technology Course Problem – APDT Examples

A major course deliverable for ITM 475, a senior-level course in Information Security Technology, is an assigned problem that requires multiple team participation. This course teaches Information Assurance (IA) and the domains of the Certified Information Security System Professional (CISSP 2009). IA deals with protecting and defending information and information systems by “ensuring confidentiality, integrity, authentication, availability and non-repudiation” (Information Assurance2009). The Problem objective given to the students, charged with assuming the role of IT security professionals, was to architect, design and implement components of a basic secure intranet.

The PDT Problem driven teaching approach implemented experiential hands-on assignments, presentations and projects that progressively contributed to the final solution.
Consider the Problem to be a picture comprised of components or elements which are mini-problems. The Problem, then, is the sum and seamless integration of all the mini-problems.

The mini-problems identified by the students were the following:

2. Specification of the hardware and software resources available for usage.
3. Demonstration of Wikis for class communication.
4. Demonstration of Blogs for class communication.
5. Evaluation of open source versus industry software for web portals and the selection of Microsoft’s Sharepoint for the WebPortal software.
6. Implementation of a prototype Sharepoint webportal that has, among its many features, Wiki and Blog capability.
7. Implementation of Microsoft IIS for Active Directory and Certification Authority functions needed for secure authentication as specified in the Problem objective.
8. Implementation of a VMware virtual environment.
10. Implementation of a MySQL database.
11. Implementation of a Ruby on Rails web development environment in order to meet the needs of the overall SOET Intranet by integrating the various mini-problems.
12. Implementation of a needed Linux test bed.
13. Implementation of a faculty research hard-disk repository.

The Problem was divided into three distinct projects with three coordinated development teams using surplus servers and network switches on a gigabit communications pathway to the Internet as follows: 1) Architect the system to function virtualized under VMware, and integrate a virtual Rails environment, 2) Employ Microsoft (MS) SharePoint WSS services as the central node and interconnected via SQL script with both MS SQL Server and MySQL databases, and 3) Provide a certificate authority and implement a portable two-factor authentication process; and provide a Linux and implement a Time-date server for digital signatures. Part of the IA challenge of this defined problem was to architect the authentication process that would provide secure access for specific roles, such as administration, staff, faculty, adjunct faculty and students.

Each team created an initial Memorandum of Understanding (MOU), with the instructor acting as the client, regarding the scope, team organization, deliverables and delivery time-frame for each project. The delivery of the four projects and integrated Problem was scheduled four weeks from initiation. As work progressed, the discovery of seemingly insurmountable obstacles that threatened the success of the overall project heightened team frustration levels. The successful delivery of the intended solution of the Problem was in jeopardy. The concern by all was not only to deliver Project 1, 2 or 3, but the successful inter-operation of all three comprising the Problem.
Specific instances of where agile project management had to be employed, and, hence, where APDT was utilized were the following: 1) Team 3 had to reduce the scope of its project, 2) Team 2 encountered seemingly insurmountable obstacles, 3) Team 1 had to adjust to include the members of Team 3, and 4) all three teams had to adjust to on-going limitations and failure of the hardware.

4.3 Team 3 Reduced the Scope of Its Project

Half-way through Project 3, a key team member was sent out of state by his employer. The Time-date stamp server feature assigned to this student could not be given to another. The Team re-negotiated with the client (the Instructor) and determined that this feature was not on the critical path for successful completion of the Problem. Hence, by agreement, and modification of its MOU this feature was deleted, the team combined with Team 1 and successfully completed the remainder of its tasks.

4.4 Team 2 Encountered Seemingly Insurmountable Obstacles

The Team successfully installed .Net Framework 3.0 and SharePoint WSS 3.0 but emphasized that SharePoint could not execute SQL scripts even though it was based upon the MS SQL database. Likewise, there was no way to interface MS SQL or MySQL to SharePoint. The Team resigned itself to not be able to deliver the terms of the MOU and insisted that the client’s objective was not realizable with the specified product, MS WSS SharePoint. One member of the team, however, kept searching and discovered that SharePoint, by default, does not contain any database connections (SharePoint 2009). However, with another MS product, Office SharePoint Designer 2007, it was possible to access both MS SQL and MySQL databases, which the team successfully downloaded and demonstrated.

4.5 Team 1 Adjusted to Include Members of Team 3

Refer to 4.3, above, for the circumstances that required a team management adjustment. This left two teams to successfully complete the Problem on schedule.

4.6 All Teams Adjusted to Hardware Limitations and Failure

As frequently is the case in university (and industry) settings, computer hardware availability is limited and IT professionals implement whatever might be supplied. Servers were configured as functional components were identified but this did limit ambitions of the teams. All of this, again, required agile adjustment of plans.

The final result after four weeks, however, was delivery of an operational basic intranet with five servers and seven VMware virtual servers providing the required services. This could only have been achieved through APDT that taught the students how to accomplish what appeared to be “impossible” and to become better prepared for the reality of the real-world workplace.
5. PROBLEM DRIVEN TEACHING IN PROGRAMMING LANGUAGES

As educators, our role is to facilitate students' learning. Of course, this is easier said than done. Unfortunately, learning doesn't happen overnight. We need to find creative ways for our students to increase their long-term retention of knowledge. A well-known Chinese proverb states that: "Tell me and I forget; show me and I may remember; involve me and I will understand". The key here is the involvement of the students so that they will get the big picture, the fundamental idea that we are trying to convey as teachers.

In that sense, both "Problem Based Learning" and PDT"Problem Driven Teaching" bring the key involvement factor by introducing a problem to the students to solve. However, these two approaches differ in their natural progress. While the first one promotes the direct student involvement throughout the process, the second one not only requires students’ engagement with the issue in their hand but also promotes the educators to be a guiding figures, and major key players to monitor their students' progress. Definitely, both approaches have a certain place in education, and probably as educators, we utilize both techniques in our way of teaching.

In his inspirational 1988 paper, Stephen Wolfram mentions the fact that the essence of education is interaction, and this does not mean canned programs and canned classes. He emphasizes that the interaction will have to come from people since AI based computer programs are still far away to communicate with people in a meaningful way. The human touch is still has the extreme importance in education.

In my (O.Tigli) programming languages classes, I try to take advantage of face-to-face communication by guiding students throughout the learning process, by covering fundamental topics and learning outcomes in each and every session. In these sessions, we go through little excursions in computer science, and try to grasp the concepts of lexical analysis, parsing, semantic analysis, and code generation by using initially small but growing examples. I also give them a short-term project to work on. Sometimes an alternative project requiring advanced programming skills is given as an option, as well. Besides all of these, I also try to maintain a simple supplemental web site to provide my students useful online materials including class notes and pointers to the other sites related with our topic. My observation is that this approach is working nicely and increasing the retention level for the students and creating good understanding of the topic on hand.

6. PERSPECTIVES ON AGILE PROBLEM DRIVEN AGILE TEACHING

Within the broad APDT framework multiple perspectives are encouraged. However, considerable emphasis is placed on agility in teaching strategies. Adaptation of a PDTroblem-Based teaching approach to suit the learning levels and styles of the students is one of the essential concepts behind APDTAgile Problem-Base Teaching. It must consider both the individual student as well as the combined characteristics of each team. Finding a successful teaching path that can benefit the full range of student competency
levels is one of the most challenging obstacles in teaching. It is important to bring weak groups and/or individuals up to a suitable level of competency and allow enough flexibility for the advanced groups and/or individuals to continue in the development of more advanced competencies. This can be addressed by paying attention to needs of an individual student in a variety of ways including individual assignments or examination questions that offer “bonus” points. Typically, only advanced students will tackle this type of problem.

A combination of team and individual assignments can vary to promote the development of individual writing and problem solving skills. Simpler team assignments that insure group competencies in basic skills can efficiently develop these individual skills through active problem solving while also allowing the development of basic team skills. The level of problems assigned for team-based problem solving can be perceived by different groups of students as ranging from easy to difficult. This reflects the ranging level of skills possessed by the individual students. Individuals in each group may also reflect differing levels of knowledge. Should all the low level students be put together, or should each team have a distribution of students with basic, intermediate or advanced skills? Usually, students have some knowledge about each other’s skill levels and personalities and pick each other based on their personal preferences. Often, there is a tendency for the exceptional students to isolate themselves from the struggling students, thereby denying struggling students the benefit of their knowledge.

One of the most widely used and important Program Learning Outcomes (PLO’s) is that “The student will demonstrate a capability to work productively in a team environment.” Another standard PLO is that “The student can demonstrate college level written and oral communication skills.” By integrating team solution presentation immediately after a problem-based session, students practice and develop these critical skills. In an extension of PDT problem-based teaching, students are required to present their solutions to the rest of the class, after a problem solving session. This serves in the development of their presentation skills as well as their logical thought processes in problem solving. Some teams simply distribute the problems among the members and do little to develop team skills or benefit from problem-based learning. By requiring that the team’s solution presentation occur immediately after the problem-solving, and only assigning one problem during a problem solving session, teams are forced to work together on a single problem. Various levels of difficulty can be incorporated by giving each team a set of increasingly difficult problems and letting them pick which problem to solve. While this may allow a lazy, but advanced skill level, group to avoid solving a challenging problem, it is more likely that a team will desire to assert their superior problem solving skills to the class through their presentation.

Within a broad range of interpretations of APDT certain clear guidelines evolving. The practitioners of APDT realize that certain propositions are more important than others:

1. Problems that match course learning outcomes are better than famous problems that poorly match the learning outcomes.
2. Analyzing feedbacks from students is more important than declaring student centered environments.

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3. Dynamically adjusting teaching strategies to learner’s goals and preferences is more important than following a teaching plan.
4. Teaching activities are driven by realistic problem solving, feedbacks from students and learning outcomes rather than by a strict schedule or mandate.
5. Demonstrating problem solving strategies on sample problems is more effective for teaching/learning than lecturing on them.
6. Dynamically combining multiple strategies in multiple models is more effective for teaching/learning than relying on a single pre-planned strategy.

One of the authors (A Datta) will be testing the APDT approach for teaching cyberinfrastructure (CI) to the biology students under CIBRED (CI-TEAM Implementation for Biological Researchers, Educators, and Developers), an NSF funded project. Teaching engineering concept to biologist and other non-engineering students is always challenging (Datta, et al., 2009). Nevertheless, the impact of CI in education is such that the Office of Cyberinfrastructure (OCI) at the National Science Foundation has established a rich source of educational and research materials through TeraGrid (TeraGrid, 2007) to meet the 21st Century's demand for scientific talent. Materials are freely available through CI/TeraGrid (Kay, et. al., 2008). Additionally, OCI put forth the CI-TEAM (Cyberinfrastructure Training, Education, Advancement, and Mentoring for Our 21st Century Workforce) program to aid education initiatives directed toward this new workforce. CIBRED is one of the funded collaborative projects (awarded to O. Crasta of VBI with A. Datta as a collaborator) of this OCI initiative. Courses are now being developed in a collaborative way using multidisciplinary approach integrating scientific and technology information from a variety of disciplines The focus is to teach students from diverse disciplines for learning some essential concepts on computer technology in the context of application of cyberinfrastructure. These courses developed for K13 & K14 levels will be offered in an innovative classroom setting for hands-on experimental learning with a focus on solving a scientific problem as a team. However, such an approach will be effective if the instructor follows the agile teaching technique to facilitate forming the students group working on a specific scientific problem.

7. CONCLUDING REMARKS: SETTING THE STAGE FOR EXPERIMENTAL STUDIES

Agility in teaching is generally advocated in several ways by many authors (Glickman, 1991; Dey et al., 2007) although it remains a challenge in practice for many teachers. Emerging tools and techniques would make it easier to deal with this challenge. Teachers need to perform their teaching with sufficient agility in order to adjust their strategies to problem solving environments and learner’s goals, styles and preferences.

The unique combination of PDTroblem Driven Teaching and aAgile teaching makes it resilient so that it thrives in a wide variety of environments. In order to measure the success of APDT it is necessary to conduct experimental studies in controlled environments. With deeper understanding of the issues, we are now better prepared for conducting our experimental studies on the effectiveness of our teaching methodology. Initial indications are that students as well as teachers benefit from APDT.
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Prerequisite Skills Testing as an Indicator of Student Retention

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Abstract

The results from a prerequisite skills exam, administered in a Solid Mechanics course in the sophomore year of the Aerospace and Mechanical Engineering degree curriculums, are evaluated as a possible identifier of at-risk students in an effort to increase student retention. The prerequisite skills exam was first implemented over two years ago in select engineering and math courses as a type of mastery exam, allowing students multiple attempts to pass the exam for credit towards their grade. This exam was largely created in an effort to boost student achievement in core engineering courses, but is also expected to be a useful self-assessment tool in anticipation of the next ABET visit. There are currently pressures to identify at-risk students and subsequently increase student retention through a variety of interventions, especially at a small, private university that is funded primarily through tuition dollars. Select results from the Solid Mechanics prerequisite skills exam are compared against a variety of factors, including drop-out rates, change of majors, and performance in both the Solid Mechanics and overall degree program performance. The study concludes that failure to pass the prerequisite skills exam can be a useful indicator for at-risk students.

Introduction

The Aerospace and Mechanical Engineering undergraduate degree programs at Embry-Riddle Aeronautical University (ERAU) in Prescott, Arizona, are somewhat traditional four-year undergraduate engineering degree programs. The Prescott campus of ERAU may be categorized as a “teaching institution,” where the engineering faculty place emphasis on instructor-student interaction, design experiences, and hands-on laboratory learning.

Student retention is receiving increasing interest at Embry-Riddle, especially in recent months with the troubled economy. This is not a unique position for a small, private, tuition-driven university such as Embry-Riddle. Many such institutions are anxiously awaiting a full understanding of the effects of the economy on enrollments for the next academic year, which is viewed by many as quite uncertain due to both student difficulty in finding adequate student loan providers, as well as the possible inability of students to afford typically higher tuition and fees at private universities lacking state support. Since there is widespread recognition that enrollments may be at best flat in many engineering programs, and have been for quite some time, increasing retention is seen as one of the most viable methods for increasing total enrollment.
In fact, retention of students in engineering degree programs has received significant attention for quite a number of years. As an example, a search of the online ASEE Annual Conference Proceedings from 1996 to the present returned 180 papers with the word “retention” in the title, only a few titles of which were not referring to the topic of enrollment retention. As another example, in a 1997 paper Moller-Wong and Eide cite Pascarella and Terenzini’s claim that some 3000 studies on retention were conducted in the past 20 years (prior to the publication of this source, obviously). While some studies and writings have focused on minority retention and general retention strategies, much of this work has been focused specifically on the retention of freshmen.

It has been long recognized that the freshman year is the most crucial opportunity for retaining students not only in a specific degree program (engineering in this case), but also in keeping students enrolled in higher education. Many programs enroll first-semester freshmen in an Introduction to College and Degree Program-style course, perhaps with a faculty member who may also serve as the students’ academic advisor. A growing number of engineering programs enroll freshmen in a first-year design experience, with the aim of introducing students to the stimulating challenges of the design process early in their education, instead of only fundamentals courses such as calculus and physics and thereafter hoping they retain enough interest in engineering to continue towards typically more motivating courses in later years. Efforts at improving freshmen retention through supportive advising have been reported. And clearly, many programs coordinate all of these efforts and more into multi-pronged approaches in a significant and time-consuming endeavor to improve enrollees.

The College of Engineering at the Prescott campus of Embry-Riddle has undertaken many such measures over the past years. A College Success course has long been a part of the freshman curriculum (optional for freshmen, although heavily recommended), the course content of which undergoes periodic review by the faculty to facilitate improvement. The College of Engineering Professional Advisor (who assists the students’ primary advisors, which are the degree program faculty) has been moved from a central campus advising facility to be co-located with the engineering faculty, and now works closely with all faculty members. Separate freshman design courses in different engineering disciplines were merged into a common-core freshman design course in 2004 to enable students to experience a wider range of engineering topics early in their education, with the aim of increasing student retention.

The Prescott campus of Embry-Riddle has long had in place a week-six mid-semester deficiency reporting system. However, the reports don’t go out to the student and academic advisors until usually week seven or eight, and by the time the academic advisor gets the student into his or her office to discuss the deficiency, it may be well into week eight or nine of the fifteen-week semester, and perhaps too late to affect meaningful change for the student. As a supplement, the College of Arts and Sciences is developing and implementing an early-warning system, with some emphasis placed on freshmen retention. As the College of Engineering is considering similar options and alternatives, it is recognized that some emphasis should be placed on student retention at the sophomore level, which is the other significant block of students deemed to be at risk for changing majors or leaving school.
Sophomore engineering

Embry-Riddle students refer to the typical second-semester sophomore schedule as “the gauntlet,” which includes courses in dynamics, solid mechanics, fluid mechanics, and differential equations. While Statics could be thought of as the first “real” engineering course where students solve the type of problems that appear in so many subsequent courses, many students are overwhelmed by the preponderance of such engineering problem solving during the semester following Statics. Some faculty view the “gauntlet” as one of the most critical semesters in an engineering student’s education, and students with weak study skills, lack of true interest in engineering, and poor preparation in fundamental courses often flounder in these courses for several semesters before eventually dropping out of the engineering program. Therefore, this semester is critical to student retention.

The author has taught the course in solid mechanics for eight (8) semesters at ERAU, which last included the Autumn 2008 semester. During this time, the author has found many students lacking in the necessary fundamental concepts from prior courses. The inadequate preservation of skills and knowledge from one semester to the next has been noticed by many instructors in the engineering degree programs at ERAU, although this is certainly not unique to our program or institution. In the case of Solid Mechanics, the most important prerequisite course is unquestionably Statics.

The author was approached several years ago by the Associate Dean of Academics at ERAU to help develop interest in prerequisite skills exams in a few courses on a trial basis, and the author took part in these trials. These prerequisite skills exams are based upon the ideas behind “mastery learning” methods. Techniques based upon mastery learning include Keller’s Personalized System of Instruction (PSI), which has been of periodic interest within engineering education. Examples of such exams based upon mastery learning concepts may be found in the literature.

Prerequisite skills exam

The first prerequisite skills exam for Solid Mechanics was created during the Autumn 2006 semester and implemented for the Spring 2007 semester, with the aim of forcing students to review prerequisite concepts before encountering them in Solid Mechanics. In this exam, the students are allowed multiple attempts to pass the exam, which is offered six or seven times during the first three weeks of the semester. Students receive credit towards their grade in Solid Mechanics, amounting to 5%, which is one-half a letter grade. Credit is only received for a passing score on the exam. A passing score is a minimum of fourteen (14) correct answers out of sixteen (16) total questions, and the 5% towards the Solid Mechanics grades is all-or-nothing.

The sixteen questions cover concepts carefully selected to encourage students to prepare for Solid Mechanics by reviewing necessary prerequisite knowledge, primarily from Statics. Examples of prerequisite skills are:

a) Calculation of the force in a structural member of a simple two or three member truss.
b) Calculation of the shear force at an arbitrary location in a beam.
c) Calculation of the second moment of area with respect to the centroid.
d) Understanding the concepts of static determinacy and static indeterminacy.  
e) Prediction of the shape of a bending moment diagram for a given shear force diagram.

An example question is shown in Figure 1. The follow-on question asks the student to calculate the second area moment of inertia with respect to the centroids of the same cross-section. The above synopsis of the prerequisite skills exam was first provided in a 2008 ASEE paper by the author, where additional details and an analysis of student performance may be found.

Student passing rates for the prerequisite skills exam

The prerequisite skills exam (PSE) is presently continuing, and has become a regular part of the Solid Mechanics course, with the exception of Solid Mechanics as taught during the seven-week summer term by another faculty member. The exam was given this Spring 2009 for the fifth consecutive semester during the regular academic year. The author administered the PSE for two sections of Solid Mechanics, but is not the primary instructor for either section during the Spring 2009 semester. During these five semesters of closely following the results, the author has noticed two important items. First, the passing rate is decreasing. Table 1 provides numbers of students enrolled in Solid Mechanics and the number of students not passing the exam.
Table 1. Students not passing PSE by semester

<table>
<thead>
<tr>
<th>Semester</th>
<th>Students enrolled in Solid Mechanics</th>
<th>Students not passing PSE</th>
<th>Percentage not passing PSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2007</td>
<td>58</td>
<td>3</td>
<td>5.2% (12.1%)**</td>
</tr>
<tr>
<td>Autumn 2007</td>
<td>27</td>
<td>2</td>
<td>7.4% (18.5%)**</td>
</tr>
<tr>
<td>Spring 2008</td>
<td>56</td>
<td>11</td>
<td>19.6%</td>
</tr>
<tr>
<td>Autumn 2008</td>
<td>38</td>
<td>8</td>
<td>21.1%</td>
</tr>
<tr>
<td>Spring 2009</td>
<td>75</td>
<td>22</td>
<td>29.3%</td>
</tr>
</tbody>
</table>

* Seven attempts allowed
** Corrected for only six attempts

The first two semesters the PSE was administered, the author provided students with one additional (a seventh) opportunity to pass the exam, and that affected the passing rates (four and three additional students passed the exam during these two semesters, respectively). This seventh attempt was only offered at the last moment each semester, after the sixth offering was completed. The author then decided to stay with the declared six maximum opportunities thereafter. When one adds these additional passes to the “Students not passing PSE” column, for the sake of equivalent comparison (these are the figures shown in parentheses in the last column), the trend is still evident. Each semester, a slightly higher percentage of students did not pass the PSE. Inspecting certain results not presented here, it appears that this decreased passing rate is generally not due to students attempting the exam fewer times, as was first suspected. It may be that students are preparing less for the PSE, or that students are less prepared from prior course work. Whatever the case may be, this has not been investigated further at the present time, but it is a noteworthy and disturbing trend.

The second thing the author has noted is that those students not passing the PSE were always student that performed poorly in Solid Mechanics, and usually did poorly elsewhere in their academics. Two general explanations can be offered. 1) These students are severely underprepared from prerequisite courses, such as Statics. 2) These students lack the motivation to persevere in a mastery-style exam, and more importantly lack the motivation to complete an engineering degree in our department. The first problem is indicated by the students that attend most or all opportunities to take the PSE, but never achieve a passing grade. The second problem may be observed with students who take the PSE only once or twice, and appear to more-or-less resign themselves to not passing the exam, and perhaps do not like the idea of being pushed to achieve a certain level of mastery of the material. The author recalls one direct questioning of a student who had not attended any of the out-of-class offerings of the PSE. The student said that he “did not believe in the prerequisite skills exam.” The author is to be commended for keeping a cool head. Cynical views aside of such a student attitude towards the PSE, it is worth noting that this student dropped out of ERAU shortly thereafter. It is clear that student attitude played a role in this retention failure.

Student achievement in Solid Mechanics

The prerequisite skills exam appears to be a harbinger of things to come in Solid Mechanics. Table 2 shows the final outcomes of those students not passing the PSE. Obviously, the final grades are not yet in for the Spring 2009 semester, and these outcomes cannot yet be reported. A grade of “W” is a withdrawal from the course, typically given because the student was doing
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poorly, and a grade of “AU” is an audit of the course, also typically given because a student was doing poorly and elected to switch the enrollment to audit the course for no letter grade. The number preceding the grade gives the total number of students receiving that grade.

Table 2. Final grades for students not passing the PSE

<table>
<thead>
<tr>
<th>Semester</th>
<th>Students not passing PSE</th>
<th>Solid Mechanics grades of those not passing PSE</th>
<th>Students passing PSE but receiving D, F, AU, or W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2007</td>
<td>3</td>
<td>C, D, W</td>
<td>7</td>
</tr>
<tr>
<td>Autumn 2007</td>
<td>2</td>
<td>F, W</td>
<td>9</td>
</tr>
<tr>
<td>Spring 2008</td>
<td>11</td>
<td>C, 3D, 2F, 5W</td>
<td>3</td>
</tr>
<tr>
<td>Autumn 2008</td>
<td>8</td>
<td>3D, 3F, AU, W</td>
<td>9</td>
</tr>
</tbody>
</table>

The first observation is that a student who does not pass the PSE rarely passes with what might be seen as an acceptable grade in Solid Mechanics. Most students not passing the PSE receive Ds, Fs, or elect to withdraw or not take the course for credit. Even though the exam is worth only 5% of the Solid Mechanics grade, which is one-half a letter grade, students have not shown the ability to recover and obtain an A or B in the course, and only rarely obtain a final grade of C. However, there are still a significant number of students who manage to pass the exam and still do not perform adequately in Solid Mechanics, as evidenced by the last column in Table 2. A noteworthy fact, not shown here, is that most of the students that received poor grades yet passed the PSE, indicated in the last column in Table 2, had difficulty passing the PSE, taking many attempts to pass the exam.

An interesting observation can be made upon considering both Tables 1 and 2 together, that while the enrollments in Solid Mechanics are typically lower in Autumn compared to Spring, there are more poor grades given during the Autumn semester. Most students on track to graduate as originally planned take Solid Mechanics during the Spring semester, while students taking it during the Autumn semester are often lagging behind due to poor performance in certain critical prerequisite courses. This generally poor performance in the degree program requirements appears to continue in Solid Mechanics, evident in this higher percentage of students performing poorly in Solid Mechanics during Autumn semesters.

Two of the seven students who passed the PSE during Spring 2007 but received a poor final grade were students who passed the PSE on the seventh attempt. All three of the students passing the PSE on the seventh attempt during the Autumn 2007 semester received a poor final grade also. This might indicate that additional opportunities beyond the sixth become less useful as learning tools for Solid Mechanics.

The PSE as a retention tool

It appears that students who do not pass the Solid Mechanics PSE are not the type of students who can recover from this deficit and perform well in the remainder of the Solid Mechanics course. This can therefore be a warning sign to the instructor that these students need immediate attention if they are to be influenced in a positive manner by faculty and advisors. However, upon digging deeper into these students’ transcripts, it appears that the PSE performance is an
It is not possible to directly compare these students against each other. The number of Ds, Fs, Ws, and AUs include all grades on the student’s transcript, including the Solids (Solid Mechanics) grade. Some students may have transferred credits and those transfer grades are not included here, and obviously the students who took Solid Mechanics during the Spring 2007 semester, and are still currently enrolled, have likely taken more classes than those students taking Solid Mechanics in the Autumn 2008 semester, having had more opportunity to perform unsuccessfully and tally more poor grades. Regardless, certain trends are clear.

Many observations can be made from Table 2. First, quite a few of these students did not take advantage of the full number of opportunities to take the PSE, especially during the Spring 2008 semester. While the statistics for the current Spring 2009 semester are not shown here, the conclusion is similar. Many students essentially elect to fail the exam, whatever the reason may be. Second, almost all of these students have accumulated a track record of poor performance. In fact, some of these students have assembled spectacularly poor transcripts. These students often manage to barely hang on, for an excessive number of semesters, and do themselves no favors when they do not heed the advice given by their instructors and advisors to shape up or ship out, in so many words. It should be noted that a grade of D is considered passing for most
classes at Embry-Riddle (perhaps unfortunately), although students are encouraged to repeat classes in which they receive a grade of D.

Students with such transcripts are clearly at-risk. While only one of these students from the Autumn 2008 semester is currently on probation, the author knows enough about the rest of these students to predict that at least three or four are rapidly nearing serious academic trouble, or are likely to be leaving the degree program shortly. There are additional students from the other semesters who also appear to be nearing the end of their academic career. However, we should also consider the remaining students in this table who somehow manage to graduate to be at-risk in another sense. It is difficult to imagine that students with such transcripts will be able to find the type of job that they have trained for. Further, it is probably not in Embry-Riddle’s best interest to have many of these students representing our academic programs.

Finally, while it is clear that the students who do not pass the Solid Mechanics PSE should be identified as at-risk students, it is realized that failing the PSE does not identify all students who end up performing poorly in the Solid Mechanics course (see Table 2). However, when data similar to those in Table 3 are assembled for students who have passed the PSE yet failed to perform adequately in Solid Mechanics, it is usually observed that these students have performed somewhat better in their other classes when compared to the student records in Table 3. Therefore, these students perhaps may not, as a group, be viewed as at-risk with quite the same urgency.

**Summary**

The prerequisite skills exam implemented in the author’s Solid Mechanics course has produced many qualitative benefits, documented elsewhere. An additional benefit that is now being explored is that it may help identify a significant number of students who are at-risk, or likely to become at-risk, of changing degree programs or leaving the university (and perhaps higher education altogether). The author and other faculty are considering a range of identifiers as aids to retention efforts. The prerequisite skills exam implemented in Solid Mechanics appears to offer such an indicator, although results should be tracked for additional semesters to offer a more complete depiction of student achievement as indicated and predicted by this exam.

**Bibliography**


Biography

David Lanning is an Associate Professor of Aerospace and Mechanical Engineering at Embry-Riddle Aeronautical University in Prescott, Arizona.
Application and Practice of Sustainable Development in Engineering

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Abstract— In recent years there has been an ever increasing need for sustainable design. However sustainable design sometimes may be in conflict with existing design standards. The topic that this study addresses is the ethical dilemma between design standards and Sustainable design. This is a newly arising conflict resulting from the recent “green” Movement. This is a new challenge facing the modern engineer. This is a problem that the new generation will have to learn to understand and deal with.

Index Terms— sustainability, renewable energy, waste minimization, and green building.

I. INTRODUCTION

The duty of an engineer first and foremost is always the health and safety of the public. Specifically Canon 1 which states “Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.” In general design standards have been written and constructed to help engineers uphold this standard of protection of the public either by negligence or unethical conduct. However the duty of the engineer goes well beyond health and safety. A major concern in the modern world is the sustainability of our modern life style. This is where the term “Sustainable Design” comes from. The Government Sustainable Administration (GSA) has defined sustainable design in the following manner: “Sustainable design seeks to reduce negative impacts on the environment, and the health and comfort of building occupants, thereby improving building performance. The basic objectives of sustainability are to reduce consumption of non-renewable resources, minimize waste, and create healthy, productive environments. Sustainable design principles include the ability to: optimize site potential; minimize non-renewable energy consumption; use environmentally preferable products; protect and conserve water; enhance indoor environmental quality; and optimize operational and maintenance practices. Utilizing a sustainable design philosophy encourages decisions at each phase of the design process that will reduce negative impacts on the environment and the health of the occupants, without compromising the bottom line. It is an integrated, holistic approach that encourages compromise and tradeoffs. Such an integrated approach positively impacts all phases of a building's life-cycle, including design, construction, operation and decommissioning”[2].

II. METHODOLOGY

It may arise as an ethical dilemma torn between conflicting principles of design standards and sustainable design. The Internet Encyclopaedia of Philosophy defines Ethic in the following manner: “The field of ethics, also called moral philosophy, involves systematizing, defending, and recommending concepts of right and wrong behaviour. Philosophers today usually divide ethical theories into three general subject areas: Met ethics, normative ethics, and applied ethics. Met ethics investigates where our ethical principles come from, and what they mean. Are they merely social inventions? Do they involve more than expressions of our individual emotions [3]? Met ethical answers to these questions focus on the issues of universal truths, the will of God, the role of reason in ethical judgments, and the meaning of ethical terms themselves. Normative ethics takes on a more practical task, which is to arrive at moral standards that regulate right and wrong conduct. This may involve articulating the good habits that we should acquire, the duties that we should follow, or the consequences of our behaviour on others. Finally, applied ethics involves examining specific controversial issues, such as abortion,
infanticide, animal rights, environmental concerns, homosexuality, capital punishment, or nuclear war[1]. By using the conceptual tools of met ethics and normative ethics, discussions in applied ethics try to resolve these controversial issues. The lines of distinction between met ethics, normative ethics, and applied ethics are often blurry. For example, the issue of abortion is an applied ethical topic since it involves a specific type of controversial behaviour. But it also depends on more general normative principles, such as the right of self-rule and the right to life, which are litmus tests for determining the morality of that procedure” [4]. This paper is an examination of the key issues in the ethical conflict that may arise in the ever growing need for sustainable design. Some key ethical issues must first be highlighted before exploring the more specific ethical issues surrounding sustainable design. Let us first explore the 2nd Canon in the ASCE Code of Ethics “Engineers shall perform services only in areas of their competence”[5]. This represents a dilemma quite often and over a range of circumstances. The ethical conflict comes either from over zealously seeking work in an area that the engineer is not qualified, or from ignorantly accepting work without properly researching the qualification required to aptly perform the task. There is one very notable caveat to this rule, an engineer who is wholly incompetent should perhaps seek another line of work that they are qualified for [2]. In the Fundamental Principles of the ASCE Code of Ethics the third principle reads “Engineers uphold and advance the integrity, honour and dignity of the engineering profession by striving to increase the competence and prestige of the engineering profession”. This particular passage especially applies to those engineers who find themselves in a position of instructing and training young and aspiring or student engineers and is one of particular weight and importance. There is another area of this ethical dilemma to explore. That is the duty of the engineering firms to educate their engineers in the newly evolving sustainable design technology as it becomes available. Programs such as “The Leadership in Energy and Environmental Design” (LEED) certification are often supported by employers. Many firms will foot the bill for taking the LEED exam and becoming a LEED Accredited Professional.

III. RECOMENDATIONS

Sustainable design is an inseparable, dynamic, concentrated, and necessary effort to continue the modern way of life. The United States Green Building Council(USGBC) explains sustainable design in the following way “The Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ encourages and accelerates global adoption of sustainable green building and development practices through the creation and implementation of universally understood and accepted tools and performance criteria.”5 It is through programs such as LEED that engineers can confidently move into sustainable design and avoid ethical issues with out of date design standards. LEED is the forefront in sustainable “green” design. Many design firms are onboard with sustainable design, it has in fact become a selling point for consultant services. LEED is at this point in engineering history the first system to allow for engineers to have standards for sustainable design. The ethical conflict will diminish with time as standards are developed, amended and revised to reflect the need for sustainable design [1].

IV. CONCLUSION

Why do engineers focus with such zeal on "engineering ethics?” Ethics are ethics. Have we, by creating a set of ethics for our professional lives as engineers, made the concept of ethical behaviour so complex and confusing that we fail to act in ways consistent with moral principles when faced with an ethical dilemma? Studies show that there is a set of guiding universal principles that if properly applied would provide guidance for dealing with ethical dilemmas. In theory, the study of engineering ethics should not be necessary if engineers were well founded in the application of these principles. Because of the complexities involved in ethical dilemmas, engineers must develop their ability to apply moral intelligence (knowledge of what is right) when we are under pressure in real-life situations. The way we learn to apply this moral intelligence is by studying ethics so that when we are faced with an ethical dilemma we can reply in a manner that is consistent with these universal principles” [5].
V. References


