AC 2009-1625: THEIMPACT OF SCAFFOLDING ON STUDENT SUCCESS IN A PRECAPSTONE DESIGN COURSE

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The Impact of Scaffolding on Student Success in a Pre-Capstone Design Course

Abstract

This paper summarizes four years of active development of a pre-capstone design course at a large state university. Three changes to course structure resulted in large positive changes to the success of the course and improvements in learning outcomes. The most significant impact has arisen from changing the focus of the pre-capstone course from completing projects that utilized specific knowledge domains of electrical engineering to defining and modeling the design process by establishing project milestones which follow the design process. A second change that had large positive impact on student success is developing resources to improve team functioning, matching team size to project complexity, and creating a project manager role on each team. Finally, changes to the learning environment which mimic an actual professional workplace and reduce the barriers to completing design projects have proven effective. Adding and improving methods that scaffold students’ skills in engineering design have resulted in a project success rate that improved from the 60% range to nearly 100%. This increase in the success rate is mirrored by increases in other metrics used to evaluate the course including reflective statements from students, rubric based grading of written artifacts, and scores on a summative examination testing design skills. Lessons from the evolution of this course offer valuable insights to other programs who wish to better prepare students for capstone courses.

Introduction and Background

Design as an activity is increasing in importance in undergraduate engineering programs both due to ABET criteria and an overall recognition that engineering needs to be more hands-on. From freshman courses to the traditional capstone programs design is often seen as by proponents as a necessary aspect of learning engineering and, as such, plays a unique and important role in many engineering programs. Unlike courses which focus on acquisition of narrow, domain-specific knowledge, design courses often emphasize application of a broad spectrum of knowledge. The importance of design, particularly capstone, courses arises both from their purported impact on students and because of their disproportionate role in assessment and accreditation in many programs. Despite the importance of design courses their format varies widely and outcomes are not standardized across programs. The goal of many design courses is to teach students the process of design—for example see—and/or practice applying domain specific knowledge to a design project. Although rarely discussed, at a deeper level faculty want design courses to be developmentally transformative; i.e. help the student actualize themselves as an engineer by taking on the role of an engineer and actively participating in the culture of engineering. Teaching design courses is difficult and time consuming for faculty. This paper presents a case study of a series of interative, ongoing changes to a capstone design course, and emphasizes three changes that significantly improved student learning, project success rates, and student evaluation of the value and utility of the course and required minimal investment of faculty time. This work falls under the theoretical framework of action research.
In 2005 the author was tasked by the department head to redesign the first of two courses in the two semester capstone design sequence. This course is taken by first-semester electrical engineering seniors with the goal of preparing them for a subsequent capstone design course where they engage in independent, team-based design projects. In 2004 the capstone course consisted of a series of projects performed by individual students in electronic circuit design. The projects were rigorously and tightly defined, and grades were determined by quantitative performance metrics (i.e. signal to noise ratio, accuracy of gain, etc.). A large number of students were unable to complete the projects satisfactorily resulting a high failure rate and/or large numbers of students withdrawing from the course. A survey of students who had completed the course revealed several issues, predominately the amount of work required for minimal reward and that most students felt unprepared for the design experience. Typical comments by students were “...I felt like my previous classes did not adequately prepare me for the class” or “all of the undergraduate level courses did not build up to this course. This was like ‘wanting to fly without even knowing how to crawl’”. This evaluation showed that change was needed, but how not to implement effective change.

The first experience of teaching a capstone design course is both worrisome and frightening to many faculty, the author included. Capstone courses are demanding of faculty time, drawing effort that would otherwise to into research or other courses. Time is spent both in preparation and management of projects as well as face-to-face meetings with students. Perhaps most worrisome is the fact that few faculty members, including the author, have formal preparation in teaching capstone design courses. The breadth of experience necessary to successfully design and manage a capstone course is found in relatively few individuals, necessitating involving colleagues or outside experts to supplement the faculty member’s own knowledge. Fortunately several texts that cover the design process have been released recently, providing central repositories of material that was previously distributed over many sources. However there is still relatively little research on what distinguished effective design courses, or on successful practices that can be adopted to meet program specific course outcomes.

Process for Continual Improvements to Capstone Course

Faced with teaching a design course for the first time and with little time to research effective practices at programs that might have similar outcomes, the author decided to begin with a course that fit his personal conceptions of design and met with overall department and ABET goals. This course was, however, to be only a starting point for a course that would evolve through small, iterative improvements. Starting with the first iteration of the course feedback was sought from students, teaching assistants (TAs), and other faculty on the effectiveness of the course. Feedback was obtained by an extensive “After Action Review” (AAR) held during final exam week and after final grades had been submitted for students in the course. The instructor and TAs were available for a four hour period and students were invited to come by and voice concerns and possible improvements. Depending on semester 30% to 50% of students provided feedback during these after action reviews. Detailed records of suggestions were kept and the instructor and TA’s acted on those that seemed feasible and would fit the overall course goals and available resources.
Over the four years (eight iterations) the course has been taught three of the changes made to the course have proved extremely valuable. Most of these changes required a relative small investment of time and resources; those that were more time intensive have produced resources that are freely available to other programs to adopt. These changes include: replacing loosely structured problem-based learning with a cognitive apprentice approach, providing resources to improve team function, and reducing barriers by changing the working environment. Each individually has resulted in positive changes to the course outcomes and is discussed in detail in subsequent sections. The paper concludes with a summary of changes to outcomes and student learning over the eight semesters the course has been offered.

Change #1: From Results to Process

Like many engineering faculty, the author is results-oriented, and these beliefs shape his teaching philosophy. In this context “results-oriented” means that at the end of a project something should work and the results of the effort need to be demonstrated by the student team. A large number of capstone courses use project demonstrations to measure project success. However in order for novices to obtain more than engineering knowledge is required, novices require a valid process which must be understood and adhered to by the participants. In early after action reviews a large number of students alluded to “being so close to success but not making it”. Another common sentiment was that the teams had made a large number of avoidable mistakes, none of which was fatal in and of itself but which in combination doomed the project. Reflecting on these statements and making inquiries of other faculty and students in the program it was discovered that nowhere in the degree program was there formal instruction in the process of engineering design. Comparisons with programs at peer universities found similar curricula. Information on the design process is available in several textbooks that have been published in the past five years.

There were two hurdles to adoption of more formal design processes in the capstone course. The first was choosing a process which meshed with course goals and would fit with the time constraints of the course. A simplified design process was developed—drawn from reference 3, and shown in Figure 1—and used as a basis for the design project. In addition to the design process shown in Figure 1 a separate taxonomy based on this model was developed to measure student achievement. The second hurdle lay in the perceived value of such instruction to students. To determine whether students would find formal instruction in the design process valuable, adding these elements to the course was suggested to students during the AAR’s; most stated that such formal instruction would have little value in and of itself.

Figure 1: Simplified engineering design cycle used for teaching design in the capstone course.
As a result of these discussions two changes were made to the course. First quasi-formal instruction in the course was provided during the first half of the semester through directed reading assignments in the design process using selected readings from Ford and Coulston’s *text name* paired with active learning during weekly classes. The goal of this change was to familiarize students with the design process and resources they would need during the team project. Second, the design projects given to student teams were broken down into a series of sequential steps with milestones at the conclusion of each step.

The milestones of the design project were related to the simplified design process shown in Figure 1. Some milestones were graded individually; i.e. each student received a separate grade. Other milestones were team grades; each member of the team received the same grade which was weighted by participation and peer evaluation scores (see subsequent sections). The combination of individual and team grading is vital for creating functional teams. As shown in Gantt chart format in Figure 2, there were five stages of project evolution teams went through: 1) developing a block diagram, 2) researching individual’s portions of the project, 3) constructing prototypes, 4) integrating individual systems to a functional whole, and 5) refining the functional device into a working unit. These five stages allow student teams to go through several project iterations, critical to successful design.

Each stage of the project is separately scored using rubrics. Since a successful project outcome requires that each stage of the design process be completed successfully, students must receive a score of 70% at each stage before they are allowed to proceed with the next stage of the project. Teams or individuals that do not score above 70% are given feedback on mistakes or areas that were not sufficiently addressed and resubmit work once errors are corrected. Late penalties accrue to work that is past the deadline and teams are encouraged to submit milestones before the deadline.

![Figure 2: Simplified Gantt Chart of Design Project](image)

The first step in the eleven weeks devoted to the design project is for the team to research then develop a block diagram—i.e. functional decomposition—of their project. Teams are given two weeks to create a block diagram after which they meet with TA’s and the instructor to discuss their design. This design critique is scored using a rubric and feedback is given to the team. In creating the block diagram teams are asked to estimate the difficulty of each block of the project, assign blocks to individuals on the team, and ensure the workload is spread evenly among the team. The block diagram grade is shared among the team and is approximately 10% of the overall project grade. A summative examination is given to teams over their block diagrams; this is discussed in detail later in the manuscript.
After the teams create a block diagram of their project, individual students research how to implement the function of the block(s) assigned to them. This research phase asks students to explore alternative implementations as well as model their circuits using electronic CAD software; This stage represents the research and modeling phases of the design cycle shown in Figure 1. A short, circa two page, written report is submitted by students when they meet individually with TA’s at the completion of the research phase. As with each stage of the project if students are unable to demonstrate competence they must address deficiencies of their work. The research stage is approximately 10% of the overall project grade and given to individual students rather than the team as a whole.

Following successful research, each student prototypes the block(s) they are responsible for. Here each team member demonstrates they have a working design for their block by showing that each of the block of the design functions independently. Students are responsible for measuring input and output signals from the block. This demonstration corresponds to the Unit Test phase of a test vee diagram \(^3\). There are no restrictions on how a prototype will be constructed and the expectation communicated to students is that significant redesign will take place after the prototype demonstration. The prototype stage corresponds to the first iteration of the fabricate→measure→communicate steps of the iterative design cycle shown in Figure 1. Students who are unprepared for the capstone design course usually are identified at the prototyping phase; fewer than 5% of students fail to eventually pass prototyping. The prototyping stage is approximately 15% of the overall project grade and points are awarded to students individually.

Following successful demonstrations of individual blocks as prototypes, the team as a whole integrates all the blocks into a (hopefully) functional prototype, corresponding to “Integration Phase I” on the Gantt chart of Figure 2. This demonstration corresponds to the Integration Test phase of the test vee diagram \(^3\). At the completion of this phase of the design, the team demonstrates a functional project and presents measured data and specifications available in a format suitable for an informal presentation. The expectation is that this system should be fully operational, although minor “bugs” are acceptable provided they are known, the causes are identified, and a plan is in place to repair them. Due to the complexity of projects typically assigned in the course the team fabricates this phase of the design on a printed circuit board to ensure reliability. Again the project is scored using a rubric by the instructor and TA’s and a score of 70 or above in needed to advance to the final phase of the project. In this first stage of integrating individual contributions, teams undergo a rapid run through the complete design cycle of Figure 1 as they research changes needed to their individual blocks, model their circuits, build and test a printed circuit board, and finally communicate the results. This phase is worth approximately 10% of the overall project grade and the score is awarded to the team as a whole.

The final phase of the design project (Integration Phase II) is to work the bugs out of the first integration phase and produce a final version of the project to professional standards as shown in Figure 2. Again students make iterative improvements to their design by going through the design cycle of Figure 1. At this end stage of the design cycle teams are expected to give a formal public demonstration of their project. The demonstration and project are scored using a rubric and are worth approximately 25% of the overall project grade. The team also must create
a datasheet for the project to formally communicate the results of the project to customers. The datasheet accounts for an additional 15% of the project grade.

In order for student teams to successfully conclude projects on the aggressive schedule of Figure 2, various methods of scaffolding the design projects have been developed. These include the rubrics previously mentioned, which are given to students at the start of the project. The project schedule is provided in the form of a Gantt chart (see Figure 2). Additionally a series of project check-lists has been developed that walk students through several of the fabrication processes. For example a checklist for construction of a printed circuit board has been developed that has reduced the number of times students need to recreate work due to avoidable design errors nearly to zero.

There are several issues that can negatively impact this model. One is when the completion of blocks needs to be sequential rather than in parallel. To address this the projects assigned try to minimize the number of sequential blocks. When a sequential set of design tasks are needed, the instructor, TA’s, and project manager identify these on the team’s Gantt chart and try to identify as many tasks as possible that can be completed in parallel. To date this has not posed a significant problem. Another of the critical issues in capstone design courses that require students to complete functional project is what to do in the case that a project fails to work. Since failure is always possible in engineering projects, teams that failed to produce a working project suffered a point reduction on their final demonstration grade that corresponds to a drop of one letter grade. This point reduction is in addition to other point reductions at earlier stages of the project. Up to half these points can be earned back by creating a “failure report” that detailed what the failure was, technical reasons for the failure, and organizational reasons the team failed. Each individual student also writes a detailed personal reflection on how their actions contributed to the team’s failure. This technique has been extremely effective in minimizing resentment among students and allowing students to experience failure in a “safe” environment.

An alternative scenario for failure is that one or two individuals on the team fail to complete their portions of the project, putting the successful efforts of the remainder of the team at risk. The key to resolving this issue is to identify potential failure points as early as possible. The structure outlined above allows for evaluation of individual performance since the research and prototyping phases of the project are performed by individuals and graded individually. Since problems commonly begin to be identified in the research phase, it is possible to provide additional scaffolding to at-risk students. Students who are unable to complete the research and prototyping phase drop the class at this point since they are aware they will receive a failing grade; this is an uncommon occurrence. Since this affects the team, the project manager is responsible for making alternative plans in the case one or more students cannot complete their portion of the functional decomposition; the project manager’s role is described below.

Change #2: Working on teams: Peer Evaluation and Project Management

The second significant iterative change in the capstone design course that resulted in positive changes in learning outcomes has been to improve the support mechanisms for working on teams. Three changes to the course have had a large impact on how well teams function: ensuring all students have a needed role, providing regular opportunities for peer feedback, and
creating a role of project manager on each team. This section discusses peer feedback and the role of project manager. Ensuring students can contribute unique skills to the team will be discussed in detail in the next section.

Teams were formed by the instructor based on cumulative grade point average and self-reports by students what times they were available to meet. Teams, to the extent possible, had maximum overlap of hours free and heterogeneous grade point averages. It has previously been reported that in order to have effective teams it is necessary to provide feedback to students on their performance on teams. To provide students feedback on their performance at regular intervals an online, electronic peer-evaluation system was used that was previously developed by the author. The peer evaluation uses behavioral anchors in questions due their reported efficacy in improving student responses. A full peer evaluation consisted of five separate elements (modules) to obtain student feedback. The five elements of the peer evaluation include:

1) Valuation: a Likert (1-5) scale rating of team member attitude and value.
2) Work: a numeric reporting by peers on the perceived work put forth by team members on team tasks as a percentage of total work. Tasks included design, fabricating the project, debugging and error checking, contributing to written reports, and maintenance roles.
3) Effectiveness: two separate Likert (1-5) ratings are completed by students. One is designed to measure the perceived Effort and the other the Results of team members’ effort. The ratio of these is used to define a team member’s effectiveness. This module was newly developed in fall 2007 and was not included in previous semesters.
4) Comment: an open-ended text box which allows students to give anonymous feedback to team members.
5) Overall: an overall effectiveness rating given as a percentage of the expected contribution put forth by each team member.

Except on the numeric reporting of total work students do not rate themselves. The overall effectiveness rating system provided a limited number of points to ensure that students did not simply rate all their team members at the highest possible rating value.

Student teams performed peer evaluations at nominally two week intervals. Due to the length of the peer evaluation instrument full evaluations were only performed twice during the semester, near the beginning and end of the design project. Interim evaluations consisted of an overall rating and written comments. Once all students submit an evaluation and the evaluations are approved by the instructor, the web-based system provides students feedback on team performance as their mean score on each of the sections of the peer evaluation as well as the mean and standard deviation of the scores for the entire class. Students are also able to view comments from peers on their performance, but do not know who provided the comments. Thus students receive feedback on their performance at regular intervals. It is not known how many students viewed this feedback or how seriously it was considered by students, but anecdotal evidence indicates at least some students do view and reflect on peer evaluation scores. Viewing peer evaluation scores also provided the instructor insight into team function over the course of the project.

The final, and potentially highest impact, change to how teams were organized came about as the result of comments from the electrical engineering department’s external advisory board. In
discussing changes to the capstone design course, the advisory board strongly supported teaching design processes and identified a lack of understanding by graduates on the importance of process in engineering organizations. One member commented that the department could do their organization a real service by providing some, but not all, students experience in project management. To implement this suggestion team size was increased by one (from 5-6 to 6-7 students) and one student took on the role of project manager. The team’s project manager has several responsibilities, but the two most important are to facilitate the work of the other students on the team and identify potential problems early enough in a project that actions can be taken to address them by the TAs and instructor.

Each team nominates two students to serve as project manager. The project manager is chosen by the instructor following short interviews with the students. The major selection criteria are maturity and engagement. The responsibilities of the project manager are to: 1) obtain resources for the team, 2) allocate manpower to different parts of the project as needed, 3) facilitate communication both within the team and to instructors and TA’s, and 4) identify problems before they become critical issues.

The project manager is graded on different criteria than the rest of the team members to ensure that rather than being responsible for part of the project, the project manager has responsibility for the project as a whole. The project manager is graded on how well they report on, and document, the team project. The project manager is responsible for the human resources of the team and both sets team assignments and teach scheduling. To ensure that this task is transparent to the instructor and the team, the project manager keeps a poster size copy of the project block diagram and Gantt chart; current and past versions of the team’s project requirements; datasheets of all components used by the team; and copies of schematics, layouts, and project reports. In addition to these responsibilities, the project managers of each team meet weekly with the instructor and TA’s and are responsible for setting the agenda of these meetings. Another role of the project fulfils is to serve as the point of contact for all instrumentation and components requests for the team. Having a single contact has significantly reduced the workload on teaching assistants. Finally the project manager has sole responsibility to archive the team’s project. At the end of the project the project manager all project documentation, files, code, and any other intellectual property of the team and archives this material. The goal of archiving is to be able to recreate the team’s project at a later date if necessary. To reflect the large amount of work required, the project manager is graded differently than the rest of the team. They are required to have half the technical responsibility, taking on fewer and less complicated blocks from the functional decomposition. These points on made up by grades on technical documentation.

Change #3: Creating a Design Environment

The final, and most time consuming and resource-intensive, iterative change to the capstone design course was trying to create an environment that supported design. Of the many changes that were made three are reported here as having a significant positive impact compared to the time and resources required to implement them.
The first, and most resource intensive, change was developing a series of training classes to teach students skills in electronic fabrication, programming, and test and measurement. Ideally students are prepared for a capstone design experience by their prior courses, but in reality it was found their background was theory-rich and practice-poor. To rectify this situation the first five weeks of the semester are spent in intensive two week mini-courses which certify students as having an acceptable level competence; these training courses are called certifications. Certifications are offered in electronic CAD, two methods of printed circuit board fabrication; surface mount soldering; test, measurement, and data acquisition using LabView; and two types of embedded controller programming and interfacing. All students are required to be certified in electronic CAD. Each certification takes two weeks. The first week is independent study of training materials and videos that culminates with a written test graded using a rubric. Scores above 80 are passing, scores between 60 and 80 require the student to address areas they need additional study in to pass, and scores below 60 fail the certification. During the second week students are given a simple fabrication or measurement task which is submitted for rubric-based grading. The same grading scale is used. Once a student passes a certification they are given access to the instrumentation on a 24 hour basis.

The second change to the environment was adopted from courses in photonics. Rather than have pre-configured lab benches assigned to teams, each team is assigned an empty bench and storage cabinet. Teams check out instrumentation from an on-line catalog to use over the course of the semester. Teams are responsible for all equipment they check out, and may access the lab on a 24/7 basis. The catalog was implemented using low cost commercial software designed for commercial e-commerce applications. Two different catalog systems are used, one for equipment and one for expendables such as electronic components. Electronic equipment is priced at actual cost, however the equipment is loaned to students rather than purchased. Students become aware of instrumentation costs through this system and additionally have a wide choice of equipment to choose from as they build a test bench for their project. The catalog for electronic components sells the components at cost plus to cover shipping. Component orders are filled within 24 hours and all components are picked up from the main department office and the cost charged to student bursar accounts.

Both catalog systems have worked effectively after a one-semester adjustment period. Several issues have arisen, however, that are currently being addressed. In checking out equipment the tendency of most students is the simply check out the most expensive instrumentation, presumably operating under the assumption that expensive correlates with better. To address this issue certain equipment requires a written technical justification to check out. Another issue was the time associated with keeping track of wires, probes, and other small items. It was decided that these would simply be left out for students to use. A similar policy is followed with solder, wire, and other expendables. The most serious issue arose with the number of electronic components to stock in-house; a balance between availability and expense needed to be reached. To resolve this issue new components are initially stocked at a low level and usage is tracked over time using the e-commerce software.

The final effective change to the design environment was in response to the large “learning curve” required for many technologies students used in design projects. To allow students to familiarize themselves with the technologies used in design projects as quickly as possible a
A series of “bootstrap” kits was developed for technologies used in the design course. Kits contain all the components needed to build a working demonstration of a given electronic technology, a breadboard, printed step-by-step instructions to build a demonstration system, and all datasheets and schematics in an electronic form. The idea behind the kits is to allow students to quickly build a functional demonstration which they can then use for further exploration and experimentation. The cost of kits is generally well under $100, much less than comparable development boards. Kits have been developed to demonstrate radio frequency identification (RFID) technology, buck boost converters, IR communication, Zigbee mesh networks, lithium-ion battery chargers, CanBus communication protocols, PIC microcontrollers, and similar technologies. An additional benefit to the kits is that teaching assistants are given time to build their portfolios and integrate new technologies into the capstone design sequence.

**Evaluation of the Impact of Changes**

As mentioned previously these changes have resulted in significant positive changes to the learning outcomes. The first evidence that changes have had a positive impact is the success rate of projects. After introducing the role of project manager the rate of project success jumped from approximately 60% (measured over six semesters, N = 12 projects) to 100% (two semesters, N = 5 projects). The projects, evaluated by a rubric, also exhibit considerably better construction and documentation. Project documentation has been considerably improved following introduction of the project manager position.

An example of a block diagram created by a team tasked with fabricating a GPS-based wireless networked sensor is shown in Figure 3, below. The diagram on the left is the initial diagram developed by the team, while the diagram on the right is that at the conclusion of the project. The diagram shows a significant increase in technical detail and sophistication.

**Figure 3:** Comparison of block diagram of one team early in the design project (left) and near the end of the design project (right).
One concern in implementing the role of project manager was that the different grading scheme used would be seen by students as somehow unfair or biased. At the end of the course reflective statements were submitted by students; in one section of these statements students were asked to explicitly address these concerns. Analysis of these reflective statements showed that nearly all students appreciated and valued the team’s project manager. Approximately 30% of students desired to take the role of project manager in future projects.

The results from the peer evaluations given across the entire semester give evidence that the efforts to create effective, cohesive teams have the intended effect. At the end of the first training part of the course students seem to rate peers based primarily on personal attributes. The ability of students to provide valid peer ratings—i.e. discernment—varies greatly between students. Statistically examining both scores received and given on the peer evaluation provides evidence for increased discernment among more competent students. One interesting finding is that different aspects of the peer evaluation were most predictive either earlier or later in the semester. In the first part of the project students rated each other on personal attributes while in the latter half of the semester students appeared to judge each other more on the amount of work they did. Correlations between scores on peer evaluations and other measures of the quality and quantity of work students did also improved over time providing additional indications students became more discerning. These results can be explained if one hypothesizes that students who are novices at design lack a frame of reference to evaluate their peers and use personal attributes. As students become more expert in the design process they can better judge peers actual contributions to projects. It is interesting to note that statistically significant correlations exist between scores given by students on peer evaluations and the results of the block diagram test discussed in the next paragraph. This provides some support to a hypothesis that student discernment of peers is related to ability to perform design. Students who give peers high ratings on personal attributes are less discerning while those who can distinguish results from effort tend to do better on tests which measure knowledge of a team’s design project.

As discussed previously an independent measure of students understanding of the design process and their teams design was a written block diagram test given in class. This test asked students to recreate the block diagram of their design project. Questions on the test were designed to measure student understanding at different points on the design process. The questions on the block diagram test also probed the focus of the nature of the student’s technical understanding; i.e. rather it was focused on specifics of the project or information general to the design project. To determine if students who better understand the design process are more competent in representing this understanding through a block diagram design characteristics were correlated with block diagram test scores. The block diagram test had significant positive correlations with peer evaluation scores, particularly the perceived effort put forth by others on the team. Over time the mean scores on the block diagram scores have risen while the standard deviation has decreased. Two effects are hypothesized to be responsible for this change. First an increasing emphasis on research and creating block diagrams is resulting in better understanding of this aspect of the design process. Alternatively the fact the test has been given in different forms for several semesters is known to students, they study for this test, and address weaknesses before the test is given. Since the block diagram test is given both to measure a student’s understanding of the team design project and also as an active intervention to ensure students learn their team’s diagram either reason represents a positive outcome.
The final evaluation of the effectiveness of changes on the capstone design course is rubric based evaluation of reflective statements written by students at the end of the course. The rubric scores students on the relevance of what they write to engineering practice, writing ability, analysis of the experience, interconnection with other classes, validity or lack of self-criticism, and awareness of ethics. Qualitative analysis of these statements indicated that: 1) the class is valued by students compared to other, more theory-based classes in the program; 2) students saw other project-based and laboratory classes as providing better preparation for an engineering career than theory-based classes; 3) students valued the certification training and believed it contributed significantly to their skills as an engineer. Overall rubric scored reflective statements increased following introduction of the project manager, but it is too early to tell if this effect is significant or not. Approximately 30% of students’ statements showed the ability to think metacognitively and describe how the course impacted them personally; approximately 20% of students show a shallow level of understanding and cite external factors rather than internal beliefs for difficulty with the design project. One interesting finding from the reflective statements is that some of the highest scoring students reported that while the class helped them understand engineering better they realize they no longer wish to be engineers. Although they intend to finish their degrees, the will seek employment outside engineering. A common sentiment among this small minority of students was that they did not really understand what engineering was when they entered the degree program.

Conclusions and Lessons Learned

In summary there are several “take home lessons” that can be drawn from the interactive changes that were made to the capstone course. First, changes to capstone courses should be made slowly and iteratively. In changing courses it is vital to set up a formal mechanism to obtain feedback from participants. Second, implementing a role of project manager on a team is extremely effective and provides the biggest “bang for the buck”. The team is better managed, the instructor gets more insight into the team status, and the project manager provides valuable documentation for accreditation and assessment. Third performing regular peer evaluations to provide performance feedback to students improves team performance. Peer evaluations also indicate that student become more discerning as the design experience progresses. Finally it is valuable to formally teach design processes and structure design projects around design processes. Past experience indicated that a “sink or swim” approach is not effective, at least at the author’s institution.

Bibliography


