

**AC 2007-267: A PRE-CAPSTONE COURSE DESIGNED TO IMPROVE STUDENT PERFORMANCE ON OPEN-ENDED DESIGN PROJECTS**

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# **A pre-Capstone Course Designed to Improve Performance on Open-Ended Design Projects**

## **Introduction**

Many engineering programs use capstone courses to expose students to open-ended design projects and to help achieve ABET outcomes. While single capstone courses are the most common, two course sequences are also used<sup>1</sup>. The first course of two capstone sequences typically prepares students for open-ended team projects in the second course. This paper describes an easily adaptable model for a “pre-capstone” course that prepares students for a team-based capstone experience in electrical engineering. The course is broadly adaptable since it has many similarities with the structure, outcomes, and grading methods of other capstone courses nationwide<sup>1</sup>.

Outcomes for the pre-capstone course were chosen based on observed deficiencies in student performance in solving open ended projects as part of a team in the second capstone course. The course was structured on a cognitive apprentice model. In the cognitive apprentice model, experts model behaviors or skills for novices who then practice the skills on their own. Continuous feedback is provided on student performance. Based on design errors commonly made by student teams in open-ended design projects, the four outcomes of the pre-capstone course are to:

- 1) Give students training, experience, and feedback from working on teams. This is mandated by ABET and most capstone programs use team-based design projects<sup>1</sup>
- 2) Give student specific design and fabrication skills. In other words the course attempts to make each student an expert in a needed skill. There are several reasons for choosing this outcome that will be explained later.
- 3) Explicitly teach time and resource management. These are taught separately using two techniques explained in the next section.
- 4) Teach a “block diagram” approach to design. The block diagram is chosen as a representative way of organizing projects and making sure that each team member has specific roles.

During the pre-capstone course the four course outcomes are modeled/practiced during three design projects that emphasize different outcomes. Specific teaching techniques and tools used for each outcome with the goal of improving student performance on team-based capstone projects. The outcomes support each other through the cognitive apprentice approach.

The remainder of the paper describes the structure and organization of the pre-capstone course then reports on the teaching techniques used to support the four outcomes. Specifically the course structure is described as a model of the design process in fitting with the cognitive apprentice approach used. Finally, a discussion of the assessment data is presented as well as resources and practice that can guide other capstone programs.

## **Course Organization**

The course was divided into three separate projects that model student learning of design using a cognitive apprenticeship. The first project trains teams in particular skills necessary for design

and models the design process for the students. Students work closely with faculty and teaching assistants during this project. In the second project student teams design a standalone portion of a larger system. During the design of this subsystem some support is given to students in the form of specifications, deadlines, and an overall block diagram of the larger system, but the design projects are performed independently by students. In the cognitive apprentice model, the second project represents independent work that is critiqued by the expert. In the third project, teams must integrate all the subsystems designed in the second project into a working system. Following the cognitive apprentice approach the faculty takes a “hands-off” attitude and student teams are given a large amount of freedom in design decisions.

The organization of projects and student teams is shown in Figure 1. Although it is well established that team performance improves with time<sup>2</sup>, the pre-capstone course reorganized teams after each project in order to help achieve the course outcomes. At the beginning of the course the students were organized into teams based on two criteria: the student’s overall grade point average and the student’s area of specialization within electrical engineering. The goal was to create teams diverse both in overall academic ability as well as ensure that teams had the skills needed to solve the design problem that was posed to them. Although evaluations show that GPA is, at best, weakly correlated with success in this pre-capstone course, there is little other information on which to form at the start of the semester. Design teams for the second project were set up first to ensure a diversity of academic skills on the design project. Next, teams for the first project were formed to ensure the second project teams had a necessary diversity of skills. Every team for the second project has at least one member with each of the six fabrication, simulation, or measurements skills from the first project.

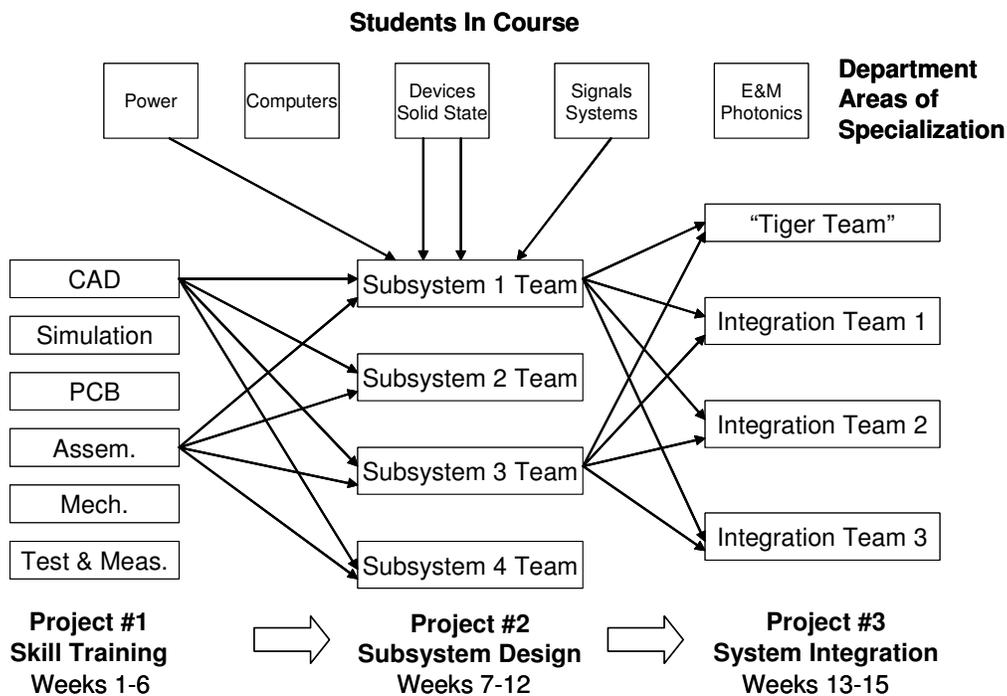


Figure 1: Organization of pre-capstone course into three projects. The arrows, representing how teams were reformed between projects, are described in the next section.

### *Project One: Students Learn Design Skills*

The first project gives students an opportunity to learn the skills needed to design and fabricate electronic systems, one of the course learning outcomes. The focus on this project is on teamwork and communication, as well as learning the skills required to build professional quality electronic systems. The students role-play different divisions at an electronic fabrication facility. A preliminary schematic diagram and design of a case or mounting system is submitted by a customer who would like a prototype of the circuit to be built. The students are divided into six teams described below. Each team is given a team contract and guidelines are discussed for team conduct regarding incomplete work, missing a deadline and missing a meeting to assure that each team member is aware of their individual responsibilities. By signing the contract, each team member agrees to the guidelines and accepts any consequences in the event of poor performance.

Each team must use one of six design skills to complete the prototype circuit. The six teams are:

- 1) Simulation: Modeling the circuit and making changes to the schematic if the circuit does not work, and determining test points in the circuit for debugging.
- 2) CAD: Turning the schematic diagram into a computer CAD file for manufacturing a printed circuit board.
- 3) Printed Circuit Board Fabrication: Turning the CAD file into a printed circuit board.
- 4) Electronic Assembly: Acquiring components and data sheets then soldering components to the printed circuit board.
- 5) Mechanical: Creating a case and other hardware to mount the completed project based on a list of specifications from the customer.
- 6) Test & Measurement: Constructing a test bench to electronically acquire data using LabView then testing and certifying the final product.

Student teams are given access to training materials on the course website. The student's comprehension of the material is then tested by an online quiz where the student must receive a grade of 90% or higher in order to pass. Students who do not pass may retake on-line quizzes with no grade penalty. After completing the first stage of training, students take a practical examination under guidance of an expert (a TA or the instructor). Although the practical examination varies for each team, each practical requires the team to perform some task to a fairly high level of competence. Practical examinations are graded using rubrics that are given to students beforehand. Once students pass the training they, are certified to use laboratory facilities and equipment. Student teams are given keys to the laboratory facility, a work bench, and locking storage cabinets.

The teams are organized to simulate the manufacturing process. The original goal was for teams to learn teamwork and the importance of deadlines by completing the design in consecutive stages. For example, the Simulation team begins work and finishes simulating the project at the beginning of the second week of class. The Simulation team then passes their schematic file to the CAD team who lays out the board and then passes a file to the PCB Fabrication team. For all six teams, including professional fabrication of printed circuit boards and error checking, the process of completing Project #1 follows the flowchart shown in Figure 2.

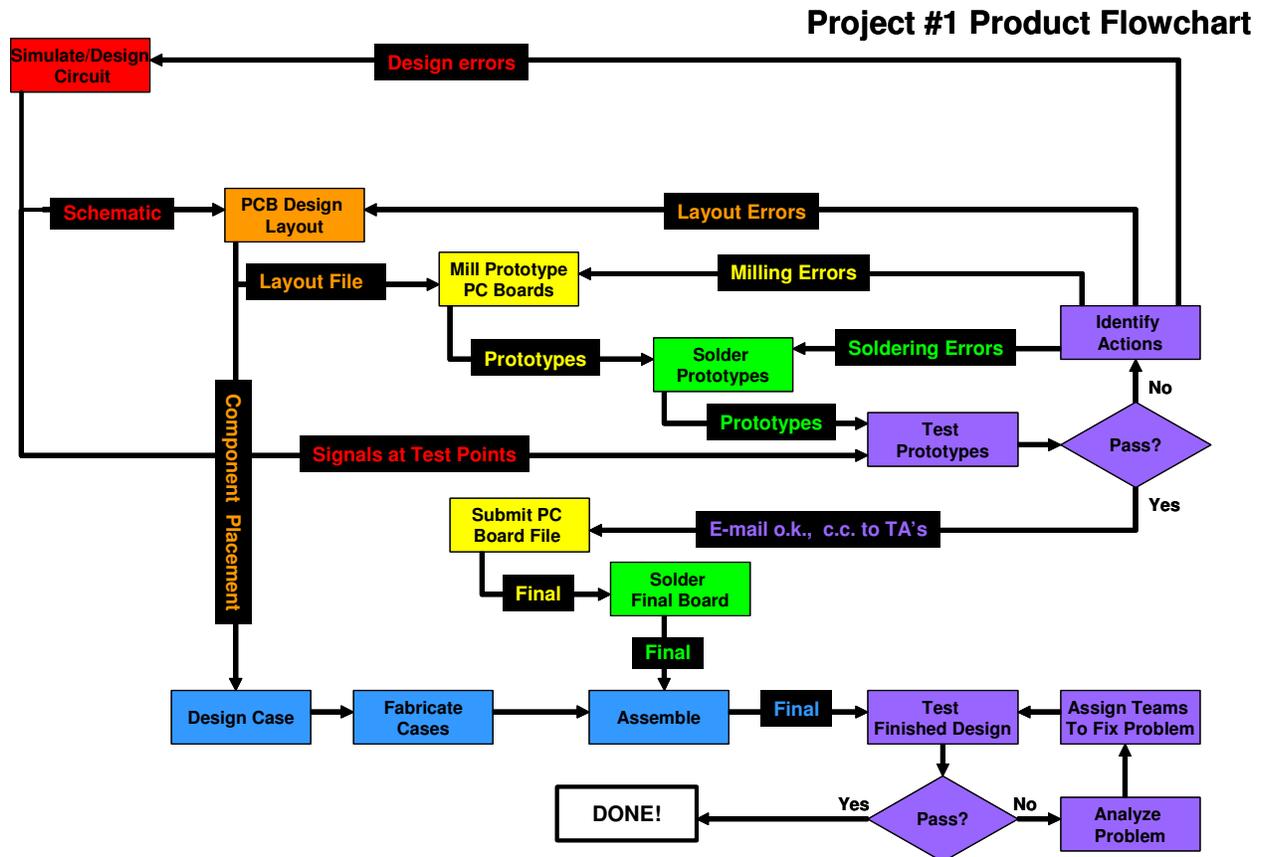


Figure 2: The stepwise product fabrication process of the first design project. This production flowchart is given to student teams at the start of the project.

The results of this first project have been mixed. Despite attempts to simplify the production process, a high level of coordination is required resulting in a large time burden on the instructor and teaching assistants. Another disadvantage of this approach is that the work load is unevenly distributed. During some periods teams are extremely busy while at other times there is little work to complete. On the positive side, the approach is authentic to much engineering design, and feedback from students indicates that about 60% of students value this project, particularly the training in skills. Students see the tightly imposed deadlines as realistic, but feel that they could have learned more if they had more time to complete the projects.

Upon completing their portion of the prototype, the team reports on the experience through a formal written report. The report is in a standardized format for all teams and is graded using a rubric which is given to students<sup>3</sup>. Teams may submit reports one time before the due date in order to receive feedback from the instructor. Feedback is given by grading the paper using a rubric and making suggestions on how to improve technical communication. Details on the grading procedure, used to help ensure the objective evaluations, are discussed later. The use of a formal report format and review of work by a “manager” both mimic engineering practice and follow the cognitive apprentice model. Scaffolding is provided by the instructor through the standardized report format and rubric with direct feedback on performance to students.

As well as a team report, each student submits a one page statement outlining their experiences on the project and completes a peer evaluation of their teammates. Students rate each team member's contribution to the team through a series of qualitative and quantitative questions. While completing the peer evaluation the student is asked to consider the work done by each student based on what was established on the team contract. The peer evaluation is electronic and students complete it on-line. After filling out questions on perceived value and effort put forth by each team member, the student gives an overall peer evaluation score that is used to scale grades. Since there is a direct weighting on grades, students tend to be conservative in their reporting. At the end of a project students are able to see their overall team rating and comments, but individual responses are anonymous. In addition to the electronic peer evaluation, each student submits a one page statement outlining their experiences on the project which can be compared with peer evaluation scores if necessary.

In summary the first project teaches students specific electronic design and fabrication skills in order to ensure they have a necessary and valuable role on the next project. It is worth questioning whether teaching electronic fabrication skills is a valuable use of student time given the fact that few students will be directly engaged in directly fabricating electronic systems. Such jobs are moving overseas as engineering and the supply chain rapidly evolves. Although most students will not directly use these skills, we feel there is value to this project. One point is that the first semester seniors who enter this course tend to take a trial and error approach to design decisions, are often careless, and do not understand the consequences of avoidable errors. By having teams fabricate an electronic system rather than just prototype it on a breadboard or simulate it in software students learn through experience that errors can be costly in terms of money and time. Students learn that errors or bad decisions tend to propagate through a project and need to be corrected early in the development phase. On average, student teams go through three iterations of project fabrication before they achieve an acceptable result. A second value to the fabrication project is that most students will work with or manage people responsible for fabrication. Experiencing the process first-hand provides valuable insight into the production side of engineering even if it is performed overseas.

### *Project Two: Using Design Skills to Build Subsystems*

The second project is the portion of the course that focuses most heavily on the third and fourth course outcomes, to teach time and resource management, and teach the block diagram approach to problem solving. For the second project, teams are organized based on the skills needed to complete each subsystem as described previously. Each team is responsible for a different subsystem, but in keeping with the cognitive apprentice approach used in the course, guidance is given to teams on the purpose and specifications of the subsystem they are designing. Each team is responsible for all aspects of their subsystem including the design, interfacing, fabrication, testing and creating a final working unit. We build on the expectations of quality taught in the first project by requiring that each team's subsystem be built on a printed circuit board and to be functionally complete and working by the end of the project.

To teach time and resource management as well as ensure student's teams have adequately thought through their design, each team is required to submit a design proposal. The design proposal outlines the problem the team is solving, proposes multiple solutions, provides a

preliminary design for each solution with sufficient technical detail to analyze feasibility, outlines the team organization, and provides a budget of equipment and supplies needed to accomplish the project. Key elements of the proposal are described briefly below:

- Team Organization: To demonstrate the team is organized the proposal includes a Gantt chart of the project schedule with clear deadlines both for tasks and individuals.
- Team Contract: To ensure work is equally divided among team members a contract outlines the responsibilities of each member, and what the rewards are for contributing extra work as well as the penalties for under-performance.
- Budget: To teach resource management each team submits a budget using an on-line catalog developed for the capstone courses<sup>4</sup>. Preparing a budget requires teams to choose from an array of items to construct an optimal solution, a key engineering skill.
- Block Diagram: The block diagram of the subsystem includes connections within the design as well as to and from other subsystems. Each student is required to be responsible for at least one block, helping ensure that all students are engaged in design. While teams are responsible for providing a block diagram of each of their subsystems, the instructor provides a block diagram of the overall system. An example of a system level block diagram is shown in Figure 3 below from the Spring 2005 iteration of the course in which the class constructed a “laser tag” game system similar to the MILES system used by the US Army.

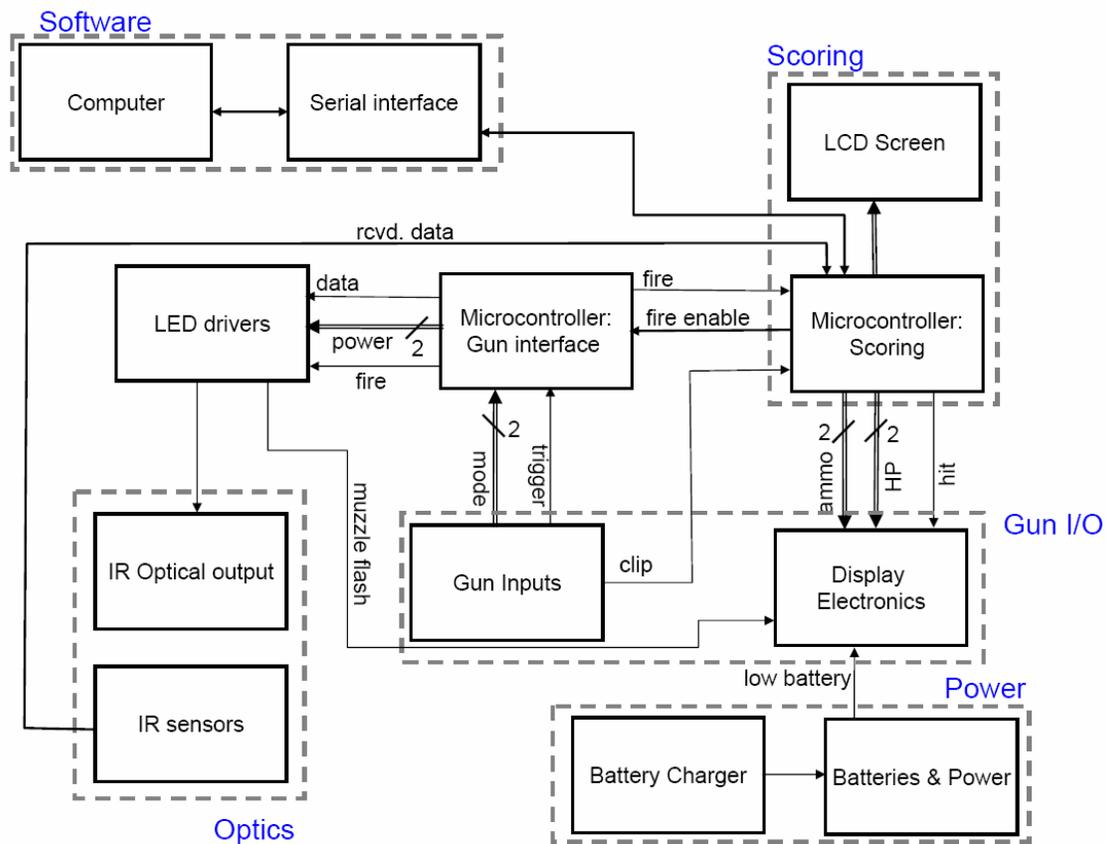


Figure 3: Example system level block diagram used in the pre-capstone course. Each block or group of blocks represents a subsystem built by separate teams.

In order to receive parts from the budget and begin the project, the proposal needs to receive a grade of “A”. The proposal is graded according to a scoring rubric<sup>3</sup>, and students are given access to the rubric. To clearly communicate expectations of technical writing, both “good” and “bad” examples of writing that highlight common mistakes made by student teams are available. If the proposal does not receive an “A”, it is returned to the team for revision and resubmission. There is no penalty for not having a proposal accepted, but in order to receive parts from the budget and begin the project, the proposal must be approved. The proposal serves several purposes. It ensures that students understand their design before proceeding with fabrication, a common novice mistake in the authors’ experience. The proposal is also an opportunity for instructors and TA’s to review team’s designs and correct errors or point out more efficient approaches. The proposal serves as a critical part of the cognitive apprentice approach. Finally the block diagram and budget in the proposal support the third and fourth course outcomes.

After a team’s proposal has been accepted the instructors and TA’s take a more hands-off approach than during the first project. Teams self-schedule time to work in the lab and are responsible for all aspects of their design. There are only two interventions by the instructor during this project. In order to assure that the team is on task, the instructor conducts surprise inspections where the progress of the team is compared to the team’s Gantt chart. It is not required that the team meet the deadlines imposed in the Gantt chart submitted with the proposal, rather if a team misses deadlines they are simply required to update the Gantt chart. The most current Gantt chart is taped on top of old Gantt charts on the front of each team’s storage cabinet to help develop awareness of how the team is progressing on the project. This more hand-off approach serves to let teams practice behaviors they were taught during the first project, determine their value for themselves, and gain experience operating independently.

On the second project, as on the first and third projects, the entire grade is based on the written team report. Research has shown that newly graduated engineers who are skilled in written communication are preferred for hiring.<sup>5</sup> Since the grade is based on communication of results, there is strong incentive for teams to explain their design process. As in the first project teams may pre-submit reports once up to 72 hours before the deadline; these reports are graded and returned to the team. All reports are graded using a rubric given to students<sup>3</sup>, and the rubrics are similar for all three projects in order to ensure consistent grading standards.

One of the difficulties in evaluating students using reports is ensuring that reports are graded objectively. To help ensure objectivity each report is graded by at least three graders from a pool consisting of course teaching assistants and the instructor. This process is similar to NSF proposal reviews with one primary reviewer and two secondary reviewers. The primary reviewer is responsible for returning feedback to the team. The grading panel undergoes a calibration session at the start of each semester to make sure grading standards are communicated and the rubric is understood by all graders. Rather than average grades from each reviewer, the panel discusses scores and reaches a consensus. Although this is time consuming for the first few reports, once the panel becomes calibrated it goes extremely rapidly and significantly reduces the grading burden on any individual. It also results in a timelier grading since there are clear divisions of responsibility. Again at the end of the second project, qualitative and quantitative peer evaluations are used to scale grades.

### *Project Three: System Integration & Marketing the Prototype*

The goal of the third project is to integrate all the subsystems created in the second project into a working system. Teams are again reorganized as described in Figure 1 so that at least one “expert” from each sub-system is on each integration team. In an ideal world, integrating the subsystems would simply require plugging the connectors of one system into another and providing power. In our experience, however, undergraduate students are not yet experienced enough to build subsystem to the specifications required and a significant amount of additional work is required to complete the system.

Two different methods have been used for organizing team in the four semesters this course has been taught under the current format. Initially the integration phase teams consisted of at least one individual who represents their subsystem. In this way, each integration team has at least one expert who can contribute knowledge to the task. This is illustrated in Figure 1 that represents the team structure. Referring to Figure 1, when this method was utilized the class created a “tiger team” with the responsibility to tackle issues that related to all teams such as communication issues between subsystems. The tiger team concept worked extremely well and each subsystem team was asked to assign their most capable member to the tiger team. In later semesters, to better follow the cognitive apprentice model, it was decided to let students choose their own teams. Students generally chose teams based on perceived tasks that would occur in the integration phase. For example, all the students with programming skills formed a team to deal with software issues. This approach has, so far, not been as successful. We hypothesize that students have not yet gained the skills necessary to form effective teams to tackle complex projects.

In both formats, students were encouraged to customize their project and to be artistic in designing the “look” of their product. Many students spent considerable time on this task and came up with creative ideas for the presentation. In keeping with the more open structure and emphasis on marketing, the report for Project #3 did not require in-depth technical documentation. Rather, teams were asked to create an advertisement with technical documentation posted on the course web site for future iterations of the project. In past semesters, students chose the format of the advertisement to be videos or poster formats such as might be seen in magazines.

### *Classroom Component of the Pre-Capstone Course*

In addition to the three projects which were done mostly independently by student teams in the laboratory, the class met for one to one and one half hours on a weekly basis. The in-class portion of the course focused primarily on non-technical skills needed for design. These include time and project management, how to report results, and how to function on a team. The purpose of the class activities was to provide support and scaffolding for the four course outcomes. The cognitive apprentice model requires that behaviors or skills be modeled before they are practiced. For this reason an active learning approach was used in most classes rather than the more traditional lecture format.

For each of the topics taught in the classroom the course required that students complete a “milestone” before class. A milestone consists of one or more short assignments that are due at the start of class to make sure the student is prepared to participate. Milestones are graded as pass/fail to communicate that after graduation, work is deemed acceptable or unacceptable rather than graded. Milestones were changed, added, or dropped each semester based on how their value was perceived by students or whether they were necessary for a particular semester’s project. A list of example milestones is: Teamwork; Defining Quality (drawn from *Zen and the Art of Motorcycle Maintenance*); Introduction to Block Diagrams; Peer Evaluations; Problem Solving Strategies; Time Management; Reading a Datasheet; and Plagiarism, Copyright, and Intellectual Property. Active learning exercises on these topics, when available, can be obtained by contacting the authors.

### **Supporting Course Outcomes**

This section of the paper discusses how the course format described above contributes to the primary course outcomes discussed in the introduction. The four course outcomes are reproduced here to frame the discussion that follows:

- 1) Give students training, experience, and feedback working on teams.
- 2) Give students necessary and specific design and fabrication skills.
- 3) Explicitly teach time and resource management.
- 4) Teach a “block diagram” approach to design.

#### *Outcome 1 Results*

In order to develop the student’s skills in teamwork several techniques were used. Case studies<sup>6</sup> on teamwork written in a fictional capstone design scenario were presented in the classroom portion of the course. The case studies presented both successful and unsuccessful teams and had students analyze the decisions that students on the teams made. As usual in teaching with case studies, no judgments were presented in the case or by the faculty member and students were encouraged to discuss the models of teamwork presented and come to their own conclusions. Reading assignments about effective teamwork were given before the case studies from the Team Learning Assistant Workbook<sup>7</sup>. The readings were supported by on-line quizzes. Reading assignments covered aspects of effective teamwork, team development, and drafting a team contract. A draft team contract was placed on the course website<sup>3</sup> and student teams were required to submit a team contract with each proposal.

At the beginning of the course the students were organized into teams based on overall grade point average and the student’s area of specialization within electrical engineering. The goal was to create teams diverse both in overall academic ability as well as ensure teams had the skills needed to solve the design problem that was posed to them. We hoped that over the course of the semester teams would learn skills that allow them to work together and be able to transfer these skills to later projects. The results of the on-line peer evaluation give us insight into how teams perform throughout the course.

Correlations between the three different sections of the peer evaluation described in the previous section show that students who were well rated by peers on one aspect of team functioning were

also rated well on other aspects. The three sections are student attitude, perceived effort, and overall effectiveness. For the data shown in Table 1 below, the class size was  $N = 17$  students. The correlations are extremely high for educational data. A model peer evaluation instrument is available which can be exported to any server which supports active server protocols; please contact the authors if interested.

	Peer: Attitude	Peer: Effort	Peer: Overall
Peer: Attitude			
Peer: Effort	0.78 (p<.005)		
Peer: Overall	0.86 (p<.005)	0.86 (p<.005)	

Table 1: Statistically significant correlations (r) between the three quantitative sections of the peer evaluation instrument.

Data from the peer evaluation also supported the conclusion that students gained skills in teamwork and were more discerning of team members as they advanced through the course. The peer evaluation scores for the three projects in one semester of the course are shown in Figure 4 below with the raw data shown in Table 2. Over the course of the semester the overall effectiveness reported value remained relatively constant, likely because this score was used to weight grades. However the perceived value of team members decreased while the variation between scores increased. Perceived value was rated on a five point Likert scale. We interpret both the decrease in score and increase in distribution of scores as resulting from students become more discerning about their team members. The variation of scores also increased for the perceived effort and overall effectiveness ratings. Both these ratings were on a percentage scale with 100% corresponding to expected effort or effectiveness. Comments reported by students on the peer evaluation support this view. Interestingly, the effort ratings fell for the second project and climbed again for the third. This mimics similar score changes in other courses taught in a similar fashion. We interpret this to mean that students are less likely to give team members high effort ratings for not contributing to the second project, and these under-performing team members adjust their behaviors following peer feedback. Again, comments submitted by students support this interpretation.

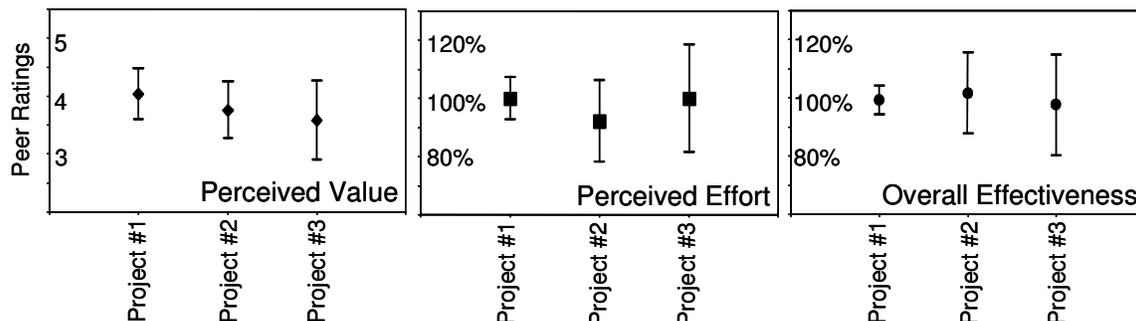


Figure 4: Change of peer evaluation scores and standard deviations over three projects in one semester.

Overall peer evaluation scores (the mean of the three overall scores) are one of the criteria used to set up teams in the second capstone course. The faculty member teaching that course does not put two low-performing students on the same team. While there is not solid data on team

performance in the second capstone course due to a lack of objective evaluation standards, faculty report a smaller fraction of problematic teams after this policy was implemented. Over multiple semesters the peer evaluation scores have been correlated with student GPA, one of the criteria used to set up initial teams. In most semesters the scores are statistically uncorrelated, particularly when low performing students are removed from the data set.

	Peer Evaluation								
	#1			#2			#3		
	Value	Effort	Overall	Value	Effort	Overall	Value	Effort	Overall
MEAN	4.06	99.9	99.1	3.78	92.1	101.6	3.60	99.9	97.5
STD	0.44	7.31	4.97	0.49	14.0	13.8	0.68	18.5	17.3

Table 2: Data from peer evaluation scores shown in Figure 4, above.

### *Outcome 2 Results*

The second outcome, giving students design and fabrication skills we observe to transfer to other projects repeatedly. As discussed previously in the first project, each student is trained in a specific design and fabrication skill. Most students transfer those skills to subsequent projects in the pre-capstone course and take on team roles that require the use of those skills.

Approximately 20% of students get trained in a second skill on their own time either because of an inherent interest or because the student with that skill on their team needs help. The quality of student work is uniformly high with a few exceptions. The move to training in design and fabrication skills as an outcome of the course was chosen to address deficiencies observed in the second capstone course as well as by necessity. We have moved to supporting mainly surface mount components due to limited availability of traditional DIP packages so that hand fabrication techniques are no longer reliable. Fabrication skills most directly transfer to the second design course where team makeup is determined by the skills each student brings. A list of student skills is given to the instructor of the second design course each semester. We observe the same students we trained taking on those fabrication roles in the second design course and using the same techniques for fabrication they were trained in.

### *Outcome 3 Results*

The least well-met of the course outcomes is teaching time and resource management. Students generally create Gantt charts and other time management aids because they are required to. Updating Gantt charts is sporadic despite the threat of points deducted for a grade. While the on-line catalog does give students a clear sense of the value of equipment and components, it does not teach the value of time, and students still make choices that are time-intensive in order to save relatively small amounts of money on their budgets. This is unfortunately reinforced in the second capstone course where students are limited to self-funding their project for no more than \$500. As mentioned previously giving students responsibility for equipment checked out has significantly reduced breakage and damage in the capstone labs. We are currently looking for better ways to incorporate time and resource management into projects.

### *Outcome 4 Results*

Finally, we report briefly on successes in teaching a block diagram approach to engineering design. We have observed that since we implemented the block diagram as a required element in proposals, provide block diagrams to students in project specifications, and give a graded test on team's block diagrams that more teams in the second capstone course are organizing projects around block diagrams. The block diagram test is described in a separate paper submitted to this conference. This approach to teaching engineering design succeeds on several levels. First, as mentioned previously, we have observed this skill to transfer although due to lack of evaluation metrics in the second course, we have not measured this directly. Second, students who perform well on block diagram tests also perform well on other aspects of design, which is seen in Table 3 below. Third, students assign work on a project based on block diagrams and the work of students who are unable to complete their blocks is more easily assessed by peers.

	<b>Block Diagram Overall Score</b>
<b>Peer: Attitude</b>	0.58 (p<.05)
<b>Peer: Effort</b>	0.70 (p<.05)
<b>Peer: Overall</b>	0.54 (p<.05)

Table 3: Statistically significant correlations (r) between the three quantitative sections of the peer evaluation instrument and the block diagram test.

Again, the correlations are high for educational data which supports the validity of the measurements. The scores students received in the block diagram test in relation to the scores received in the peer evaluations show statistical significance. This suggests that the students who received high marks on block diagram test also received high marks on their peer evaluations.

In conclusion, reorganization of a pre-capstone design course to address four outcomes that support design has shown some transfer to the second capstone course, particularly in areas of teamwork and training in fabrication skills. Students become more discerning and learn the process of design through a cognitive apprentice model.

The authors acknowledge support from the National Science Foundation through award NSF0530588. Ms. Co and Mr. Turner would like to acknowledge support from a National Science Foundation REU award (NSF0631565) which enabled them to conduct the research presented in this paper. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

## **Bibliography**

- [1] S. Howe and J. Wilbarger, "2005 NATIONAL SURVEY OF ENGINEERING CAPSTONE DESIGN COURSES," presented at ASEE Annual Meeting, Chicago, 2006.
- [2] S. G. Adams, "Building Successful Student Teams in the Engineering Classroom," *Journal of STEM Education*, vol. 4, pp. 27-32, 2003.
- [3] R. A. Cheville, "ECEN4013 Web Site," vol. 2007, 2007.

- [4] R. A. Cheville, A. McGovern, and K. Bull, "The Light Applications in Science and Engineering Research Collaborative Undergraduate Laboratory for Teaching (LASER CULT)-Relevant Experiential Learning in Photonics," *IEEE Transactions on Education*, vol. 48, pp. 254-263, 2005.
- [5] J. Large, "COMMUNICATION IS ENGINEERING: RESPONDING TO NEEDS OF INDUSTRY IN A CAPSTONE COURSE," presented at ASEE Annual Conference and Exhibition, Chicago, 2006.
- [6] C. F. Herreid, "Case Studies in Science- A Novel Method of Science Education," *Journal of College Science Teaching*, vol. 23, pp. 221-229, 1994.
- [7] D. Carr, Herman, Z. Keldsen, Miller, and A. Wakefield, *The team learning assistant workbook*. Boston: McGraw Hill, 2005.