An Innovative Multidisciplinary Capstone Design Course Sequence

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Abstract: The departments of Mechanical Engineering and Electrical and Computer Engineering at Valparaiso University have recently combined their two capstone design course sequences into a single, multidisciplinary capstone experience for all senior students in the two departments. This paper outlines the structure of the courses that resulted and describes the benefits and challenges that resulted.

The two departments decided to merge their senior design classes in 1999 based on feedback from several stakeholders. Among these were alumni who reported that they work in a very multidisciplinary environment and need to understand how to work with other engineering disciplines. A pilot study was run during the 2000-2001 academic year, and all seniors in the past two years have completed the integrated program.

The primary result of this curriculum change has been a significant increase in the quality of projects that students complete. The number of commercially sponsored projects has increased substantially since the multidisciplinary sequence was introduced, and students in the course have received national recognition for the quality of their work. Additional benefits have included closer working relationships among faculty and students in the two departments and improved assessment results for multidisciplinary teamwork skills.

Particular aspects of the course sequence such as writing design requirements, virtual prototyping, physical prototyping, testing, and reporting are described in detail. Special consideration is given to the challenges of grading individual members of a team project.

1. Introduction

Two of the most important skills engineering educators can impart to their students are the ability to design a product or system and the ability to work effectively in teams[1-3]. In particular, since the introduction of Engineering Criteria 2000 by the Accreditation Board for Engineering and Technology[4], multidisciplinary teamwork has been an active area of curriculum development at many universities[5-10]. At Valparaiso University, the departments of Mechanical Engineering (ME) and Electrical and Computer Engineering (ECE) have combined these goals together into a multidisciplinary senior design course sequence that introduces students to the fundamentals of teamwork and the design process in a multidisciplinary setting. This decision has resulted in tremendous changes to the senior design sequence for both departments, very important benefits for the students and faculty involved, and more than a few substantial challenges.

2. Development of a New Course Sequence

Prior to the 2000-2001 academic year, the senior design course sequences of the ME and ECE departments were entirely separate, with students from each department working primarily on projects related to their own discipline. While ECE students attempted to design rudimentary mechanical devices to be controlled by their electrical designs, and ME students similarly attempted to design simple electrical control systems for their mechanical designs, neither department was able to create a complete design that was satisfactory in all aspects. It was decided in the fall of 1999 that the courses should be combined together and the teams integrated across disciplines.

During the summer of 2000, a committee composed of faculty from each department met for two weeks to discuss the desired features, format, and policies of the new course sequence. Since the ECE department previously had a three-semester capstone design sequence and the ME department had a two-semester sequence, some substantial compromises had to be made. At the same time, the decision was made to increase the level of structure in the course and to provide a high level of support for the student teams. This support took the form of dedicated laboratory space, increased availability of faculty resources for advising and consulting with teams, and increased project budgets. Along with this increased level of support also came an increased level of expectation for the quality of the projects and the performance of the teams.

As a learning exercise, it was decided to run a trial multidisciplinary team by allowing an ME student to participate in the ECE senior design course and to work with a team of four other ECE students during the 2000-2001 academic year. Many lessons were learned as a result of this trial. Among the most important were:

- When members of a student team have different backgrounds and expertise, it can significantly increase the interpersonal challenges facing the team. This pilot study team, while successful in creating a design of good quality, had substantially more interpersonal conflict than any other team in the course.
- It is very important to articulate the expectations on team members of both disciplines, so that all students and advisors involved are aware of their responsibilities. Since students from different disciplines are frequently waiting for each other to complete their work, this articulation should clearly include enforceable deadlines for each task assigned.
- The projects chosen must be of sufficient complexity for both disciplines that all students involved are challenged but not overwhelmed. It is especially important in projects such as ours to be certain that the ME students are not just filling the role of computer aided design technicians and machinists, nor are the ECE students serving as

electrical technicians and soldering experts. However, it is equally important not to overwhelm students from either discipline with tasks that greatly exceed their knowledge base.

During the summer of 2001, a subset of the faculty who had originally met to plan the senior design sequence spent another week revising their plan to incorporate lessons learned from the trial study. Modifications were made to include advisors from both disciplines for each team, at least two students from each discipline on each team, and more structure in reporting progress to advisors through weekly memos and periodic oral progress reports to the entire class.

3. Teaching the Course for the First Time

In the fall of 2001, the two-credit course GE 497: Senior Design Project I was taught for the first time. There were forty students in the course, split into six teams of four, two teams of five, and two teams of three. For the two teams of three students, a particularly talented ME student was paired with two talented ECE students on a project for which they shared a strong interest.

Students were assigned to team projects based on their expressed interest in one of twenty proposed project ideas. Students with similar interest in a project were typically assigned to work together, although students were also allowed to express preferences for people they wanted to work with and people they preferred not to work with. Projects selected in the first year of the course ranged from externally sponsored projects (an electronic golf club) to internally sponsored projects (an electron microscope positioning system) and entries in national design competitions (a fire-fighting robot). In a survey completed by the students at the end of the project selection phase, 79% of the students expressed satisfaction with their project topic and 93% expressed satisfaction with the students assigned to their team.

The first four weeks of the course were spent introducing the design process and the project definition process to students. Each team was asked to work with their two advisors and a customer to define System Design Requirements (SDRs) for their project. In this way, the students were able to understand exactly what would constitute success for their team before they began to propose alternative solutions. As part of the project definition process, students began to perform research on their project topic and to learn about other similar projects that had been completed in the past.

After defining the SDRs for their project and performing initial research in their area, students were asked to propose alternative solutions to their problem. Each of these proposed solutions was then evaluated using numerical weighting of design requirements, desired project attributes, and the risk associated with each. Hybrid solutions (combinations of proposed solutions) were also encouraged, and these were also ranked on the same weighted scale. After this ranking process, teams chose their optimal solution.

Once each team had chosen the solution it felt was the best for its design requirements, they were asked to create a "virtual prototype" of the design. This virtual prototype was intended to require the students to fully design and specify their optimal solution before beginning physical fabrication of any parts. The use of development tests, simulations, component specifications, and theoretical calculations were intended to allow the team members and advisors to be confident that the chosen design would, in fact, meet all of the specified design requirements. The final section of the virtual prototype was a bill of materials, from which supplies for the fabrication of the physical prototype were ordered over Christmas break.

In the second two-credit course of the sequence, GE 498: Senior Design Project II, students began by building the physical prototype that was fully specified in their virtual prototype document. This phase of the course lasted approximately eight weeks. After the physical prototypes were complete, students transitioned to the verification-testing phase, in which they were asked to prove that their prototype did, in fact, satisfy all appropriate design requirements. This effort culminated in a Test Report, which was a written record of the tests performed and the results of those tests.

The final portion of the course sequence was the reporting phase, in which students were asked to prepare a final written report and give a final oral presentation summarizing their project work. The written reports were typically between fifty and one hundred pages long, and each oral presentation was between fifteen and twenty minutes. All faculty graded the oral presentations, while only team advisors and the course coordinator graded the written reports.

4. Grading

In both courses, grades were assigned to entire teams and then distributed by the team members themselves. This was done through the use of six Performance Reviews that occurred regularly throughout the school year. Each student and advisor was asked to evaluate each member of the team with a numerical ranking of 0-100. They were asked to account for effort, contribution to the team, and the quality of that contribution. These scores were averaged for each member of the team, and team member scores were averaged to determine the team average.

The ratio of individual rating to that of the team is called the Individual Adjustment Factor (IAF), and each team member's IAF is multiplied by the team score to determine the individual score. In this way, a student whose performance is judged by the team and the advisors to exceed the average performance of the team will receive an IAF greater than one, and his/her final grade in the course will be correspondingly higher than the team average. Likewise, a student who has performed below the team average will receive an IAF less than one, and this will lead to a final individual score less than that of the team average.

This mechanism for accounting for individual effort in a team setting does not change the average grade assigned to a team. The only way that one member of the team can receive a grade higher than that assigned to the team is if one or more team members receive a grade that is lower than the team average[11].

5. Positive Results

At the completion of the first full year of the new multidisciplinary course sequence, seven of the ten projects were judged to have substantially met all of their design requirements. Of the three projects that failed to do so, two were primarily as a result of poor mechanical design and one was primarily a result of poor electrical engineering design. Two of the failed projects, an inverted pendulum and an adaptive automobile cruise control, encountered substantial difficulty in control system design, which is a topic that needs to be emphasized more in the ECE curriculum if such projects are to succeed. As a result of this feedback, the ECE department added a course in control system design in spring 2003.

Of the seven successful projects, there were three major success stories. The fire-fighting robot team traveled to Connecticut to participate in the national design competition, and their robot won first place in the senior division, defeating over one hundred other teams. The electronic golf club group proved the feasibility of the design for their corporate sponsor, who continues to pursue the idea and has applied for a patent. The electron microscope positioning system was installed on the microscope in the biology department at Valparaiso University, and it has substantially improved their ability to do research on cell development.

In the course evaluations for the first time the courses were taught, students strongly indicated that they were able to effectively participate in multidisciplinary teams (rating this ability at 4.24/5.0), they were able to write a complete set of design requirements (4.32/5.0), design a virtual prototype (4.05/5.0), and effectively communicate their design ideas in writing (4.05/5.0) and in oral presentations (3.97/5.0).

6. Negative Results

Course evaluations for the first semester demonstrated very clearly that students felt they were being asked to do too much work for a two-credit course. When asked to evaluate the workload on a scale from 1 (Too little work) to 5 (Too much work), the average score assigned by students was 4.24. Also, students felt that they were spending too much time doing "busy work" and not enough time doing "real design work." When this was probed further with focus groups, it was determined that the primary source of their frustration was lack of hands-on fabrication of the physical prototype until the second semester.

While it is not unusual for students to claim that senior projects require too much work for too little credit, many of the faculty shared their concern. For this reason, several planned assignments in the second semester were eliminated before it was even taught for the first time. In spite of this change, course evaluations for the second course echoed the concern that too much work was being required for too little credit. In spite of the elimination of some assignments in the second semester, the student rating of workload in the course was even higher (4.57/5.0) in the second semester than it was in the first.

The second time the course sequence was taught, during the 2002-2003 academic year, the workload for the fall semester course was substantially decreased again. In addition, the previous content of the first course was compressed in order to allow students time during the last two weeks of the semester to begin working on their physical prototypes. Nonetheless, course evaluations for fall 2002 echoed the concerns of the previous year, that students are being asked to do too much work for too little credit. The course evaluation rating for the second attempt at teaching GE 497 showed workload to rate 4.75/5.0.

In addition to these concerns, students and faculty also began to express concern over the dispersion of authority in the course. With a course coordinator, two advisors and a customer for each team, and two technical consultants, eleven of the twelve faculty in our two departments were involved in the course in at least one role. When a team had a question about course policies, grading, or supply purchases, they had many different faculty to whom they could speak. The professor approached by the team typically did his best to answer the team's question as thoroughly and clearly as possible at first, but this response frequently conflicted with the response given by another professor. After several such incidences, most faculty began to send the team to talk to someone else, eliminating the risk of giving them a wrong answer. This situation frustrated both the students and the professors involved.

7. Lessons Learned and Future Course Revisions

Although evolutionary changes were introduced for the 2002-2003 course sequence, revolutionary changes are being implemented beginning in the fall of 2003. To address the concerns that students have about workload, all assignments are being reviewed to ensure that they are tied to the course objectives and to the successful completion of the course project. Furthermore, each of the two departments has located one additional credit hour from elsewhere in their curricula to be assigned to the first-semester course.

To address the problem of authority dispersion, the structure of responsibility for faculty associated with the course is being substantially modified. Beginning in fall 2003, each of the two departments will assign only three faculty to work with the course. Each of these faculty will work exclusively with just two student teams. This professor will present all the course materials to his teams, read all of their work, meet individually with each team for one hour each week, and assign all of their course grades.

In effect, there will be six parallel sections of GE 497 and GE 498. Sections coordinated by an ECE professor will be paired up with sections coordinated by an ME professor, and students in the opposite discipline from their coordinator will be given opportunities to receive technical assistance relating to their discipline from the partnered professor of their own major. In this way, each student team will have a single point of contact, a single authority for all issues related to the course, and a single primary technical authority who is much more closely monitoring the team's progress and technical challenges.

The six faculty involved in the course will meet weekly to discuss issues raised by their teams, to clarify expectations, and to seek technical expertise and materials needed by their teams. These weekly meetings will help keep the six sections well aligned, although students will still be able to rely on the judgment of a single professor.

8. Conclusions

In combining our senior design project courses, the faculty in the ECE and ME departments at Valparaiso University have learned many lessons. We have attempted to use our best judgment and to follow the feedback of students when it is clear and compelling. The structure of the course has changed each of the first three times the sequence has been taught, and further small modifications will, no doubt, continue to be necessary for several years. However, students will continue to work on substantial, real-world design projects that require a wide diversity of experience. The benefits received by those students make all the challenges well worth the effort for the faculty involved.

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