Putting the "Engine" Back Into Engineering Education - A Capstone Design Project

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Abstract

The Mechanical Engineering Department at Ohio University has recently radically transformed its Senior Design Curriculum. This change was motivated by the perception among the entire mechanical engineering faculty of the need to improve the way that engineering design is taught at the senior undergraduate level. Three separate design courses have been replaced with a single year- long course that is team-taught by three instructors. This change was implemented to improve the student’s "time on task" and to provide for comprehensive feedback on each student's demonstrations of their design skills as well as the quality of their written and oral presentations.

The class has been divided into ten learning communities, in the form of design teams. Team building and teamwork exercises, which are frequently reviewed by the faculty, have been implemented.

The design project itself involves the design and construction of a vehicle powered by an externally fired heat engine. The “best” vehicle will traverse 100 meters in a straight line in the shortest time. This combined thermal/mechanical systems design project was selected to integrate material from all of the core mechanical engineering courses and to ensure that our graduates have a basic understanding of engineering science and how it relates to the art of engineering design.

The purpose of this paper is to describe the key features of the new course and to evaluate its success in meeting its educational objectives. The “soft skills” component of the course emphasizes development of skills for lifelong learning, including research skills, teamwork skills, and communication skills. The year-long sequence of courses is being team-taught, with extensive use of a Blackboard course web site for organizing group activities, and is being monitored by referees from the industrial sector.

I. Introduction

The implementation of ABET’s new EC-2000 accreditation standards have provided engineering departments with the opportunity, and the incentive, to reassess and redesign their curricula. The faculty of the Mechanical Engineering Department at Ohio University decided in 1996 that one area in need of reform was the senior capstone design experience. At that time, each senior undergraduate student was required to satisfy the senior design requirement by completing three separate courses. One required course was a structured advanced design course in either mechanical or thermal systems depending upon the student's interests. The second course was a weekly colloquium where each student made a formal, fifteen-minute, presentation to the class and instructors. The final course in the original sequence was an independent design experience where the students teamed up with faculty, institutional or industrial sponsors to solve a "real world" design problem.

There were two major problems with the original sequence. First a single ten-week quarter of advanced design work did not provide enough time for a complete cycle of "design, implement and evaluate." Too often design solutions were rushed to completion and demonstrated without sufficient feedback from the faculty, or evaluation by the students and their peers. The second problem was that there was a wide range of variability in the types of individual design projects undertaken. Often these were little more than paper exercises where the student got little experience in actual design.

The new design sequence, implemented in academic year 2000-2001 was specifically created to remedy these problems. First, the capstone design experience is now presented in an integrated sequence of three consecutive courses. The entire senior class is divided into design teams that each begin the same project in September and demonstrate their solutions in a public competition held in May. The last two weeks of the Spring quarter are used for formal review of the performance of the projects by the students, faculty, and industrial referees. This structure provides the time on task required for a deeper learning experience.

The course is team-taught by three instructors, each of whom takes the lead for one academic quarter. Since the instructors are chosen from the full-time, senior faculty in the mechanical and thermal systems areas, and have widely divergent professional experiences, the students benefit from the continuous, day to day, interplay of the instructor's expertise and attitudes. In addition each instructor acts as team advisor for approximately one third of the design teams for the entire year.

The senior design sequence was created with three basic goals in mind. First, this course sequence was seen as the opportunity to establish and develop those activities known to deepen the learning experience for the students. Second, the course sequence was established to provide each student with a significant, professional level, engineering experience. Finally the sequence was viewed as a good tool for assessing student development and the effectiveness of the entire mechanical engineering curriculum at Ohio University. This assessment is based upon frequent student evaluations of their readiness to handle specific tasks, including both the requisite knowledge and skill and the assessment of these same attributes by industrial referees.

II. Implementation of Deep Learning Strategies

Considering these course goals one at a time, the pedagogical goal was to foster a deep learning environment. One aspect of this goal, time on task, was discussed previously. A second mechanism for deep learning incorporated in the course sequence was the use of design teams as learning communities. This year's class of forty-two students was divided into eight four person teams and two five person teams. All work is done cooperatively. The grade established for each team assignment is divided among the team members by means of a peer review assessment tool [1.]. Emphasis is placed on the need for the design team members to continuously teach each other what they themselves are learning, as well as learning from the other team member's efforts.

Each student is required to maintain a formal design notebook, and each team is required to maintain a team design file that contains memos of meetings, all design documentation and a complete project plan and schedule. The design files are accessible to everyone involved in the course. These materials are reviewed by the faculty advisors once a week and are also available on the course's Blackboard web-site for review by off-campus industrial referees. Taken together, the individual and group documentation provide a powerful learning portfolio that documents the entire design process. These documents are essential to the construction of the formal project review the students and faculty prepare at the end of the course.

Communication skills are certainly among the most important aspects of professional success. They are given a central position in the senior design sequence. Each student is required to make at least one formal oral presentation of some aspect of the design effort during the year. Each formal presentation is videotaped and is subsequently reviewed by the student and the faculty. Informal status reports are given by the student team members, on a rotating basis, every other week throughout the academic year.

Each quarter, each team prepares at least one major formal written report. These reports are presented in first draft form, reviewed by the faculty, and then subsequently rewritten until the team members and faculty advisors agree that they are of professional quality. This opportunity to iterate the solution to an assigned task until the students achieve the desired goal is perhaps, the most outstanding benefit of the extended time on task provided by this year-long course.

Computer communication skills are also intensively developed throughout the course. Faculty members and the student design teams use Blackboard to establish and maintain a communications channel with each other and with external industrial experts and referees. In addition many of the teams have established their own web pages.

III. Curricular Issues

The project assignment, the use of a externally heated engine to propel a vehicle, was selected to include aspects of as much of the traditional mechanical engineering curriculum as feasible and to match the interests of the inaugural faculty advisors. This project explicitly synthesizes knowledge and skills from both the thermal systems and mechanical systems areas.

In addition to this fundamental synthesis the project required the application of various other skills required by practicing engineers. The course focused on the development of teamwork skills, including the resolution of conflicts and the concepts of leadership and professional responsibility.

Successful completion of the project required the use of sophisticated project management techniques. Computer techniques were used to construct project plans and to assist the team members in identifying the tasks on the critical path. Throughout the year formal project schedules were created and continuously updated in the wake of manufacturing, design and testing deadlines and delays.

The ability of the students to use research tools including the web, electronic databases, patent records, and industrial codes and standards was fostered both by the instructors and by outside experts. Safety issues and the application of government regulations and professional engineering codes were explicitly addressed at each stage in the development of the design.

The topic of the project was such that a significant amount of the design decision making process required the use of sophisticated, professional level, computer simulation techniques. The information required for numerical simulation was often obtained by experiments designed and performed by student teams. One spin-off of this approach was that some of the design groups cooperated in sharing experimental procedures and data which expanded their individual learning communities.

Many of the faculty throughout the Russ College of Engineering and Technology, while not directly involved in the capstone course sequence, contributed support for the various design efforts either by direct consultation with the students or by posting appropriate information on the course website. Student's also worked with shop people, parts suppliers and vendors throughout this project making this an actual, professional level, engineering micro-experience.

IV. Implementation

The entire project course was divided into three academic quarters. The implementation goals of the first (Fall) quarter of the project were to organize effective design teams and prepare, present and evaluate a formal preliminary design and project plan. To this end, the first two weeks of the course were used to present the ideas of team work through a series of team building exercises that were suggested by industrial consultants and were available in the literature [2.]. The college's bibliographer at Ohio University's Alden Library made a formal presentation on research methods and resources available to the students. The goal and explicit constraints of the project were then assigned.

The basic technology of three alternative solution types were discussed. These options included Stirling engines, reciprocating steam engines, and steam turbines. Presentations were made by faculty and outside experts on each of these alternatives. The relative costs and benefits of each competing technology were thoroughly discussed by these domain experts and by the student groups themselves. The groups were then given guidance in techniques for deciding between competing proposals. From all of this conceptual information, each team created a preliminary design for its vehicle and power train. At the end of the quarter one member of each group made a formal presentation to the entire class on the technical details for their group's vehicle and the plan that had been developed to build it.

The goal of the second (Winter) quarter was to develop the conceptual design into a formal final design. The first step in this process was modeling. Formal instruction was presented on methods of constructing an analytical model and on the numerical techniques of simulating and optimizing the performance of the power trains and vehicles themselves. To support this effort the student groups were given informal guidance on the design and implementation of necessary experiments. In particular those groups that had chosen steam engines for their power source built boilers and established their steaming capacity. All of the groups were required to build dynamometers and prototypes of their engines and measure the torque-speed relationships for use in the required whole vehicle simulations.

As the designs came together, each team did a formal assessment of the design's reliability, manufacturability and functionality. The results of these studies, along with the results of the simulations, were then used to redesign the basic vehicle and its associated sub-systems.

By the end of the Winter quarter each student design team had to demonstrate that they had a final design that had a very good chance of accomplishing the task, could be built with the resources they had available to them and could operate safely. A second formal report was made both orally and in writing, and these reports were evaluated and reviewed by the students and faculty. Those groups that were working well together were building and testing many of the aspects of their designs at this point.

The third (Spring) quarter was devoted to building, testing, redesigning and demonstrating their designs. The actual demonstration was done at a single elimination drag race on a university parking lot. This competition was open to the public and was attended by interested members of the university faculty as well as the Board of Visitors, industrial representatives and local media. Aside from the actual competition the major task of this quarter was for each design group to prepare and present a formal written and oral evaluation of the design performance and the design effort. In particular this final report focused on the questions: How well did the vehicle's performance conform to the student's expectations? What did the design do that was not expected? How had the design evolved throughout the entire process? How could the design teams and the instructors have improved the design process. Perhaps the major advantage of providing sufficient time on task is that a formal evaluation of the year's effort can be accomplished by the students, the faculty advisors and the industrial referees. This, of course, is the critical step in the deep learning process.

V. Evaluation

Informal discussions with students, anonymous e-mail messages supported in the Blackboard environment, and anonymous student evaluations of the courses prepared by the college have provided some information as to how the student's viewed this experience. Essentially, student concerns fell into three general areas: First, they were uncomfortable with the lack of structure imposed on the course by the opened-ended nature of the design problem. Initially, they did not have enough experience to plan ahead. When a deadline for a specific task was assigned they had not yet accomplished the preliminary work that would have made it easier to accomplish.

A second cause of concern for the students was grading based upon performance rather than the usual metrics of examination and homework scores. A subjective system for grading, based upon the relative “professional quality” of the various required milestones in the design process was originally used. To even out instructor bias all required design deliverables were graded by all three instructors and the results averaged. Each student design group was then allowed to evaluate the relative contributions of each member of the group and individual grades were determined from a combination of these two factors. As the course evolved a more precise definition of professional quality was developed by the instructors that allowed the students to check off what was expected of them.

A third issue that arose was the fact that students were not entirely comfortable with the concept of instructors as guides. Many of the students expected the instructors to do the work for them, that is they demanded an immediate answer to a specific question, rather than guidance on how they themselves could find the answer to that question. Again, given time, an effective compromise was achieved. Instructors pointed out possible research paths when asked broad, “getting started” kinds of questions but provided much more specific answers to questions that arose when students were comparing ambiguous, or contradictory, results of their own research.

The instructors had their own observations of the effectiveness of this experience. The first observation was that students had a hard time adjusting to the new learning paradigm embodied in the “design experience.” As mentioned above, in spite of numerous warnings by the advisors there was a general reluctance to anticipate what was going to have to be done to accomplish the task. Time management was a continuous issue. Some other observations discussed by the instructors that arose during the course were:

- Students had difficulty in using material from prerequisite courses in a new, more general and unstructured context.
- By their senior year engineering students need to develop a more self-reliant attitude and they must internalize the need to pursue learning on their own. This is, of course, an issue that must be dealt with earlier in the engineering curriculum.
- Mechanical engineering students showed a great deal of resistance to adopting the holistic viewpoint toward design and project management, preferring instead to concentrate their efforts on specific technical details, often, irregardless of the relative importance of the technical detail to the success of the overall project.
- There was a wide variety of effectiveness among the various design teams. Some were enthusiastic and cooperative, some were much less effective due in part to internal dissensions. The group structure of the design team created many problems the students had difficulty working through.

Recommendation

If design is what engineers do, then engineering education must better prepare students for the actual experience of doing engineering. The concerns voiced both by students and by the faculty during this capstone project point out the need to introduce more professional, less structured, course work into the earlier undergraduate curriculum. As a result of this experience many of the concerns of the faculty are being explicitly addressed across the entire mechanical engineering curriculum, beginning with the freshman introductory course and continuing through the basic engineering science courses. It is hoped that as this effort progresses senior level mechanical engineering students will be better prepared to meet the challenges of their profession. This, is of course, the basic goal of the EC 2000 accreditation standards.

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