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Optimizing Student Learning in a BME Capstone Design Course Sequence

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Introduction

The undergraduate biomedical engineering (BME) program at the University of Tennessee, Knoxville (UTK) was initiated in the fall of 2000. The 136 semester-hour curriculum was designed to prepare students for a variety of careers and to meet ABET accreditation requirements. Among the most prominent of the ABET requirements is that the curriculum include a capstone design experience. For this purpose, all seniors must complete a two-course design sequence (BME 455, 469). In keeping with the model used by other undergraduate programs (mechanical and aerospace engineering) in the parent Department of Mechanical, Aerospace and Biomedical Engineering, the first (fall semester) course is a two-hour course while the following spring course is a four-hour course for a total of six semester hours of senior design. With the consistent format students enrolled in any of the three departmental majors can petition to utilize any of the three design course sequences in their curriculum depending on their technical interests.

As is true with any curriculum, the major challenge is to design and administer each individual course in a manner to maximize student learning and satisfaction. A design course sequence presents many significant challenges related to both technical content and "people issues." The manner in which these have been dealt with effectively in the BME 455 - 469 course sequence is detailed below.

Course Objectives

The objective of the BME design course sequence is for students to learn essential design methods and skills and to be able to function efficiently and effectively as individuals and as members of design teams. Specifically, students must be able to perform a comprehensive project literature review including a patent survey, and they must formulate product design objectives and specifications and develop design alternatives. Students must be able to evaluate alternative designs and select the particular design best meeting the stated objectives. Students must learn how to build, test and optimize prototypes. They must know how to present their design effectively to "management"

both orally and in written reports. Finally, students must be familiar with engineering standards and be able to assess the particular manufacturability, ethical, health and safety, economic, societal, political, environmental and sustainability issues related to a product design.

Course Content

During the first course in the two-course sequence (BME 455) students are organized into teams. The teams then select projects, complete a background investigation, formulate project objectives and specifications, develop and evaluate alternative designs and select an optimal design concept. The second course in the sequence (BME 469) offered in spring semester is dedicated to refinement of the chosen design concept and the construction and testing of a design prototype. Complete documentation including a set of (computer generated) engineering drawings is required. Both courses require a mid-semester oral report of progress and final oral and written reports.

Course Oversight

During the first three academic year cycles for the BME 455 - 469 course sequence (2000 -2003) two faculty members operating as a team served as course instructors for a total of six to seven teams (24 to 27 students) each academic year. Although the employment of two faculty members for overall course management resulted in modest course administrative burdens for each, it was found that issues of uniformity of grading occasionally arose. Beginning with the current cycle, a single course instructor is designated.

Establishment of Student Teams

Historical experience shows that given their preferences, students would like to form design teams with other students known to them and with their friends if possible. Allowing teams to be formed in this manner can result in serious imbalances in average team academic ability and in team functional effectiveness. To avoid these problems, current practice is to form teams in an academic ability-balanced basis. Team size is normally four students. Some effort is made to achieve gender balance as well which is an issue with there being a nearly 50%/50% ratio of male to female students in the BME program.

Development of Projects

During late spring semester and summer each academic year, a faculty member assigned to the task solicits senior design project proposals from all BME faculty members. All faculty are required to submit at least one project. Since student design projects can support faculty research at no labor cost, faculty often desire to promote projects of their interest. The involvement of all faculty broadens the technical basis of project offerings and spreads the technical project management burden on an equitable basis among faculty.

Student Design Project Assignments

In an initial experience in the fall of 2000, student teams were each assigned a specific project from a set developed by BME program faculty. Although the overall results were satisfactory, at the end of BME 455 student teams reported that they would much have preferred to be able to select a project from a list of suggested projects. In order to generate a high level of interest in their projects and to maximize "buy-in," in subsequent academic year cycles, a listing of potential projects greater in number than the number needed for each team to have a project was developed. The number of "extra" projects currently numbers at least 50% more than those needed so that all teams have a distinct sense that they have some choice of projects. For student teams, selecting a project "of their choice" improves motivation contributing to project success.

Project Management

A two-layer system is used to manage the BME 455 - 469 course sequence. An overall course instructor provides general oversight and oversees the formation of student teams, student team selection of projects, monitors progress, schedules all course events and grades all course work. In addition, other faculty serve as "technical advisors," who provide technical guidance to one or more design team(s). In this way, the technical advisors become virtual members of the design teams which allows closer attention to project needs than can be provided by the course instructor alone.

Course Activities

The completion of design projects requires substantial student work "outside the classroom." In order to achieve good project results for all teams, this effort must be systematically directed. During the period 2000 - 2003 students were allowed to set their own meeting frequency and times. This practice was found to often result in uneven progress among teams and for a given team throughout the semester. Based on this finding, beginning with the 2002 -2003 academic year, there was put in place a requirement for weekly meetings of each student team with the course instructor. Additional meetings with team technical advisors occurred on an as-needed basis. The weekly meetings substantially aid in the monitoring of progress and the timely solution of problems as they arise. The weekly meetings are scheduled for a 15-minute duration with additional time made available if needed. Since students know that these regular meetings will uncover lack of progress, there is an incentive to work hard enough between meetings to achieve significant results on a weekly basis.

In the first two academic year cycles of the BME design course sequence, a substantial number of lectures were delivered on design subjects from a currently in-print undergraduate design text. The students consistently reported that these lectures seemed "dry" and uninteresting and did not maintain their attention and interest. Beginning with the 2002 - 2003 academic year offering, a "just-in-time" approach is used to achieve

student mastery of essential design techniques. For this purpose, the course instructor assigns team readings from the textbook on an as-needed basis throughout each semester.

Maintenance of Steady Design Team Progress

Many significant problems can arise in the course of a two-semester design course sequence. Of prime importance is the maintenance of a high level of productivity of all student teams. A common problem is for some teams to report a team member who is "not carrying their weight." It has been found that the potential for this to become a serious problem can be minimized by requiring weekly meetings with the course instructor (discussed above) and by requiring students to evaluate their team members periodically during each course. These team member evaluations result in a score that is incorporated into final grade determinations. Another course requirement promoting uniform progress throughout each semester is the requirement to submit written progress reports on a regular basis. A final practice instituted recently which discourages weak student performance on his or her team is the possibility of being "fired" from their team for cause (and following a formal "hearing"). A fired team member must work on an assigned individual design project to earn a course grade. It is anticipated that actual "firings" will be rare, but the overhanging possibility provides strong motivation for each student to participate effectively on their team.

Grading and Evaluation

The system of grading of student work used in any course can play a strong role in providing incentive for student engagement and accomplishment. For the BME 455 - 469 course sequence, virtually all student activity is evaluated on a periodic basis and contributes a component of the final grade. Written progress reports are graded and returned to all teams to provide feedback leading to improved future submissions. Oral and written reports are evaluated with regard to content, organization and effectiveness of presentation. To encourage effective teamwork, student team members are required to evaluate the performance of their peers periodically during each semester. A form was developed for documenting these evaluations. The form includes statements such as "usually attends group meetings" with a corresponding score for each of several categories of participation. Completed forms are submitted to the course instructor who maintains confidentiality of the reported data. If two or more members of a four-person team rate a team member poorly for any reporting period, a team meeting is called in which the course instructor discusses methods for improving team function.

Conclusions

Assessments of three complete academic year cycles for the BME 455 - 469 design course sequence have guided the continuous improvement of the BME capstone design experience. The principal conclusions derived from these assessments to date are:

- A two-layer system of course administration utilizing an overall course instructor and student team "technical advisors" from among BME faculty members assures

high quality technical projects while maintaining a uniform basis for student evaluation and grading.

- The makeup of student design teams should be determined by the course instructor in a systematic way to obtain consistency with regard to student academic abilities and gender. This approach prevents the establishment of unbalanced teams and improves the competitive nature of project work among teams.

- All BME faculty members should contribute design projects and serve as project "technical advisors." Entire faculty participation offers students a wide variety of projects and improves design work oversight by supplementing the general oversight of the course instructor.

- Student teams should be able to select from a number of available projects. This promotes student team project ownership that motivates good teamwork and a high probability of project success.

- Formal lectures on design methods are not as effective for student learning as is the assignment of reading material from a design text on a "just-in-time" basis during project development.

- Formal periodic written progress reporting encourages students to conduct design project work at a steady pace with no periods of relative inactivity.

- Students should be required to periodically evaluate each member of their design team to allow assessment of individual student performance in team work. Care should be taken to encourage students to make “honest assessments” of their peers and not to contribute to the problem of “grade inflation.”

- Formal oral reporting by each design team at mid-semester (and at the beginning of the second semester course) motivates a quick start-up of projects each semester and provides an opportunity to provide feedback to teams on the effectiveness of their presentation methods before the final oral presentation at the end of each course.

Changes made in the current (2003 - 2004) academic year in accordance with the listed "principles" has notably improved the student learning experience as evidenced by an improvement in the final grade distribution for the most-recently completed BME 455 course. Future assessments and refinements are anticipated based on formal feedback on course outcomes from our "customers" including students completing the course, BME faculty, an external BME program advisory committee and selected employers.

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