

Cross-Functional Teaming in a Capstone Engineering Design Course

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Abstract - This paper describes a cross-functional teaming approach used in a computer-engineering capstone design course. Students are grouped into two sets of interdependent teams, “design teams” and “skill teams.” While designing a product, students acquire an understanding of the need for lifelong learning and the need to depend upon each other for critical skills and knowledge necessary to ensure overall project success.

Design teams are formed for the entire semester. Each team works on a specific engineering design project that involves the collaborative development and evaluation of a “product” containing an embedded computer.

Skill teams are formed from representatives of each design team. These team members acquire specific skills and knowledge needed to ensure success within the individual design projects. Skill teams are highly focused. For example, one team learns how to use Microsoft’s PowerPoint® presentation software tools. These team members take this knowledge back to their design teams, instruct design-team members in PowerPoint basics, and use PowerPoint in team presentations. Other skill teams focus on topics such as: management of class and team activities; browsing the internet to obtain information about embedded-system hardware components, software, design tools, and third-party suppliers; hardware and software standards related to embedded systems; and programmable-logic-device technologies and trends.

Introduction

ABET is scheduled to begin a three-year phased implementation of *ABET Engineering Criteria 2000* (ABET 2000) with the 1998-99 accreditation cycle; full implementation is scheduled with the 2001-02 cycle [1]. During the three-year transition period, institutions “may elect to have their programs evaluated under the current criteria or under Engineering Criteria 2000.” In the first year of this phased implementation, Michigan State University is scheduled for the next general review of its engineering programs. After careful consideration of the opportunities and risks associated with each of the options, the faculty in the Department of Electrical Engineering voted to recommend that the department move forward with plans to prepare for its next general review of its electrical engineering program by seeking continued accreditation of the program under ABET 2000. It also recommended to

seek first-time accreditation of its computer engineering program using this same criteria. With the endorsement of the department and college administration, the faculty began to develop and implement a plan to comply with ABET 2000 for the 1998-99 accreditation cycle.

Early faculty activities related to developing and implementing this plan focused on the following interrelated initiatives. The faculty:

- benchmarked selected academic programs at other institutions for the purpose of evaluating our major engineering design experience because engineering design was perceived by some faculty as a possible weakness in both the existing electrical engineering and computer engineering programs;
- identified a set of key employers of our graduates and formed an “Employer Stakeholder Focus Group” to advise the faculty as program educational objectives and assessment strategies were developed; and
- developed a “working set” of electrical engineering and computer engineering program educational objectives, to be used in evaluating the existing programs against ABET 2000.

A thorough review of the computer engineering program was undertaken by the Computer Engineering Task Force, comprised of faculty from both the Electrical Engineering and Computer Science departments. One result of these initial activities was the restructuring of the computer engineering capstone design course, a course required for all computer engineering majors. This paper describes this newly revised course and places these revisions in the context of ABET 2000 [1] and the baseline computer engineering curriculum at Michigan State University [2].

Initial Findings and Outcomes

Benchmarking Engineering Design

As part of the process of benchmarking major engineering design, twelve representative institutions were surveyed. The study was interested in determining how ABET’s major engineering design requirement was interpreted and how different institutions fulfilled this requirement. One overarching finding in this study was that there is great variability in the way different institutions interpret this

ABET requirement, as well as how this major engineering design experience is incorporated into the curriculum. Significant results of the study include the following.

- Some programs identify a specific course as the course where students gain their major engineering design experience; others identify a sequence of courses; and still others point to the curriculum as a whole.
- Some programs rely heavily on industrial advisors; others have little on no formal involvement with industry on student design projects.
- While most programs contain some form of major design project, considerable variability occurs with teaming, oral and written communications, realistic design constraints, and engineering ethics.

This benchmarking exercise suggested that our approach of offering a one-credit capstone course on professionalism, communications, and ethics followed by a four-credit capstone design course was not out of line with the practices at other institutions or with the intent of ABET 2000. However, we were able to identify a number of ways to improve the engineering design experience while retaining this curricular model. These observations led to several of the changes in the capstone computer-engineering design course described later in this paper.

The Employer Stakeholder Focus Group

Because of ABET 2000's requirement for "a process based on the needs of the program's various constituencies in which the (program educational) objectives are determined and periodically evaluated," several key employers of our graduates were contacted and asked to form the nucleus of an "Employer Stakeholder Focus Group." This focus group made a number of important observations and recommendations [3].

- It reviewed ABET 2000 and assisted in developing a working draft of the program educational objectives.
- It developed recommendations as to how employers might become involved in program assessment.
- It identified several areas for significant near-term improvement in the current programs.

These recommendations led to several of the changes in the capstone computer-engineering design course.

Program Educational Objectives and Course Learning Objectives

A working set of program educational objectives were developed for both programs. These computer engineering program objectives contain the list of items (a)-(k)

identified in Criterion 3 of ABET 2000 [1]. These program educational objectives in turn had a significant impact upon the development of the following set of learning objectives for the revised capstone course in computer engineering [4]:

Students will learn about embedded systems—i.e., electrical systems that contain embedded computers to control processes. At the completion of this course, each student should have actively participated as a member of an engineering design team and made significant contributions to achieving the team's stated goal and objectives. Each design project should involve the collaborative development and evaluation of a "product" that contains an embedded computer.

Specific team activities should include:

- a) propose an engineering design project that has clearly stated design criteria, including realistic constraints;
- b) share in the day-to-day design activities and management of the project;
- c) share in the presentation of oral and written progress reports;
- d) share in the demonstration of results at key milestones during the life of the project; and
- e) evaluate the project's progress and outcomes against a clearly articulated set of criteria.

At the completion of this course, each student should be able to:

- a) describe and understand the principal characteristics of a generic embedded system;
- b) understand the need for hardware and software standards and, moreover, access relevant standards and interpret their meaning and application;
- c) delineate the principal design criteria and constraints for an embedded system—e.g., cost, size, power, environmental factors, reliability, safety, maintainability, and reusability;
- d) describe and understand the overall engineering design process—e.g., project justification, identification of constraints, establishment of design criteria, establishment of timetables, the partitioning of work, project monitoring, and project evaluation;
- e) describe and understand contemporary industry practices and trends with respect to embedded systems and embedded system design;
- f) describe, understand, and apply key tools used in the overall embedded system design process;
- g) acquire and understand information contained in contemporary technical literature—e.g., trade journals, magazines, books, conference

- proceedings, and supplier literature—about embedded system hardware components, software, design tools, third-party suppliers, etc.; and
- h) browse the web to acquire information about embedded system hardware components, software, design tools, third-party suppliers, etc.

The embedded system emphasis resulted from curriculum review by the Computer Engineering Task Force and is supported in part through a combined research-curriculum development initiative called VESL (Visions for Embedded Systems Laboratories) [5]. These course learning objectives were developed to be compatible with the computer engineering program's educational objectives [2], with input received by the Employer Stakeholder Focus Group, and with things learned through the major engineering design benchmarking process.

Course Learning Model

Once we understood what we wanted to accomplish in the capstone computer engineering design course, our attention turned to asking the central question: "Can we re-structure the existing course to achieve these learning objectives?" Previously, the course had been taught in a lecture-laboratory format with three 50-minute lectures and one 3-hour laboratory per week. The nature and scope of the new course learning objectives suggested that this format had too many constraints. Being well aware of alternative student learning models and having had success with several strategies in other courses, we proceeded to investigate an effective re-structuring that synthesizes some of these ideas.

K. A. Smith and A. A. Waller describe the principle of "cooperative learning." It focuses on the use of small instructional groups so that students work together to maximize their own and each others' learning [6]. With formal cooperative learning groups:

- members are responsible for their own and each other's learning with a focus on joint performance;
- members hold themselves and others accountable for high-quality work;
- groups are formed for a clearly stated purpose with well understood tasks and time schedules;
- members promote each other's success and assist each other in learning;
- teamwork skills are emphasized; and
- groups evaluate themselves and how effectively members are working together; continuous improvement is stressed.

E. Aronson, et al., describe a "cooperative jigsaw strategy" [7]. Base teams are formed for the semester and reflect the overall goals of the course—i.e., the course learning

objectives. However, these teams do not remain isolated from each other because teams are formed from representatives of each base team to learn specialized skills or to gain knowledge needed by base teams. These specialized teams are formed, do their work, and dissolve. Specialized team members return to their base teams with skills and knowledge to be shared so that the base team's goals can be achieved. E. Nuhfer [8] and R. Schwartz [9] discuss the importance of "student management teams." These teams can be viewed as a specialized team in cooperative jigsaw strategy. It provides oversight of base team activities and can also be used to recommend the formation of specialized teams to acquire skills or knowledge needed by the base teams. A student management team helps with overall course coordination and improvement and brings individual base-team and specialized-team members a sense of empowerment and ownership. The emphasis is not upon the professor directing and controlling the students, but rather upon the students themselves making informed decisions about team activities and the assessment of team achievements. With these learning models, the teacher's role as a stand-up lecturer is diminished. In fact, E. Mazur suggests that the principal role should be one of listening and questioning [10]. By asking base teams and specialized teams the right questions at the right time, the teacher facilitates student learning and thus the achievement of course learning objectives. Moreover, the course learning model is representative of what students will encounter in industry. For example, Ward has documented the formation of "study groups" to facilitate staff professional development through self-directed learning [11].

Course Overview

These student-learning and course-management concepts led us to revise the capstone computer engineering design course and apply the concepts contained in [7]-[10]. We refer to our approach as "cross-functional teaming." Students are grouped into two sets of interdependent teams, "design teams" and "skill teams." Design teams are formed for the entire semester. Each of these teams works on a specific engineering design project that involves the collaborative development and evaluation of a "product" that contains an embedded computer. Each design team is responsible for the following collective activities of its team members: propose an engineering design project that has clearly stated design criteria, which includes realistic constraints; share in the day-to-day design activities and management of the project; share in the presentation of oral and written progress reports; share in the demonstration of results at key milestones during the life of the project; evaluate the project's progress and outcomes against a

clearly articulated set of criteria. Skill teams are formed from representatives of each design team. As the name implies, these teams “learn” specific skills needed to ensure success within the individual design projects. Skill teams are highly focused.

During the semester, the class of twenty-one students was divided into four design teams. Two teams designed an embedded fluid-flow control system via a ping-pong ball position controller, and two teams designed an embedded in-system programmable (ISP) logic device (PLD) programmer and tester. Two teams were chosen for each topic so that alternative design strategies could be explored. The four teams were put into a context of a single company’s engineering staff meeting a customer’s needs. Table 1 depicts this “design team matrix” model, in which rows are organized according to the product or system being developed, and columns, the design strategy being applied. The model provides some class-wide cohesion among design teams, since all four projects contained a number of common threads that facilitated project success through the use of skill teams and cross-functional teaming. Students were introduced to strategies for effective teaming, group processing, and self-assessment [12, 13].

Table 1. Design Team Matrix Model for Prototype Fluid-Flow Control System

	Strategy 1: Microcontroller	Strategy 2: Emulator
Product 1: ISP PLD programmer	Design Team 1	Design Team 2
Product 2: Ping-pong ball position controller	Design Team 3	Design Team 4

Skill teams were formed for the following purposes: a student-management team to help with overall course coordination, project planning using Microsoft’s Project® tool, and design-team and skill-team assessment; a presentation and documentation team to learn and then apply Microsoft’s PowerPoint® and Word® presentation and document-preparation software tools; a web-site construction team, which was responsible for building and maintaining a website for each design team; a team to learn about hardware and software standards; a team to learn about programmable-logic-device technologies and trends; a team to learn about browsing the internet to acquire information about embedded-system hardware, software, design tools, third-party suppliers; a team to learn about LabVIEW®—a visual instrumentation package by National Instrument’s that was used extensively during the semester

by two of the design teams to emulate embedded computers; an assembly- and C-language programming team, which was responsible for writing code for the Motorola 68HC11 microcontroller—the embedded computer used in two of the four design projects; and, finally, a team that was responsible for performing a case study on an existing commercial product containing an embedded system and for developing “product specifications” for possible future computer engineering capstone design projects.

Based on immediate needs, an initial set of skill teams was formed:

- Course/Project Management
- Website
- Documentation and Presentation
- C and Assembly Language Program Development
- LabVIEW®

Each design team has one member on the Management, Website, and Documentation skill teams. These skill teams last for the duration of the semester. Representation on the other skill teams was determined according to design-team needs; for example, design teams adopting the emulation design strategy (teams 2 and 4) were represented on the LabVIEW® skill team. These and other skill teams exist only as long as needed to accomplish a designated purpose. Students also proposed and formed new skill teams as the need arose, i.e., students began to take responsibility for creating and managing their own learning. The interaction facilitated by skill teams that crossed design-team boundaries was a key aspect of the teaming experiences gained by the students.

The course was team taught by the two authors of this paper. Two hours per week were formally set aside as “lecture time” and six hours per week for “laboratory time.” After the first three weeks of the course, lecture time was used: by the faculty to provide overall guidance and direction for the course and teams; by the skill teams to meet or present reports; and by design teams to present progress reports. The six hours per week for laboratory time represented a time when skill teams and design teams could meet and plan activities or do their required work. Students, however, had unlimited access to the laboratory. The two faculty met for up to one-hour each week with the student management team to help with overall course coordination and team assessment. Feedback to these teams was provided each week during the lecture time.

To support a true capstone design experience in a single semester, it was essential to start quickly. In the first week of the semester, students were introduced through demonstrations to an array of tools, technologies, and components pertinent to the design projects. Students also began journals to be used as engineering workbooks for personal self-assessment. In the second week, design teams

and initial skill teams were formed, and a session on was held. By the third week, students participated earnestly using cooperative learning in the classroom to gain some technical background in embedded systems. As early as the fourth week, both skill and design teams were giving oral progress reports. The enthusiasm and pride of the students was evident in their presentations. Students had already begun to develop a sense of ownership and team-strength. The design teams received a request for engineering design project proposals (RFP) during the fourth week, launching them into the details of their projects.

The work environment and experiences of students were very similar to what they would eventually encounter after graduation. In fact, student journal entries included: "This course is different than any I've taken." "This is how it really works in industry." While designing a product, students acquired an understanding for the need for lifelong learning and the need to depend upon other team members for critical skills, which they themselves may not personally possess, to ensure overall project success. They developed a sense of pride in their work, as well as a sense of empowerment. Many developed a sense of ownership of the product being designed, of the ideas generated, and of the teams themselves. This, in turn, drove students to work harder and to set higher standards for themselves and others.

A website having complete details about the course is maintained at <http://www.egr.msu.edu/classes/ee482>.

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