Capstone Design Management Perspectives of Industrially-Trained Faculty

Hodge Jenkins 1 and Laura Moody 1
Mercer University

Abstract

New faculty observations and lessons learned from managing a two-semester senior capstone design course are presented. The perspective of this work is from a faculty manager who was formerly involved with project management in corporate environments. The goal of the multi-discipline course is to provide a capstone design experience in the various engineering disciplines represented. Issues that arose to challenge the students and professor are discussed. Similarities and differences to project management in industry are also presented.

Introduction

A two-semester capstone design project in engineering is the referenced set of courses discussed in this paper. Successful completion of a capstone project is required for all senior engineering students at Mercer University, School of Engineering. Each semester's course is two credit hours. The primary objective of these projects is to provide the students with a realistic engineering experience having relevant technical design content for each team member. Presented in Table 1 is a larger list of course goals.

In the first semester, the students form teams (typically 2 to 4 people), propose a project, schedule tasks, design and analyze solutions. Each group chooses a different project. Sponsored projects are available from professors and industrial clients. The first course culminates in a written Preliminary Design Report and oral presentation where the proposed final design is fully documented and presented, based on engineering analysis and evaluation of potential solutions. If successful, the teams are given approval to proceed to build and test their selected design in the following semester. Construction, testing, re-engineering, and evaluation of their design are presented in a final project Critical Design Report and oral presentation.

While Table 1 lists the goals for both courses, the specific goals for the second semester course are different than the first. The first semester is primarily a paper study with limited testing to decide the appropriate design approach to the problem. Proposal, specifications, engineering calculations, status reports, design report, and preliminary test plans are formulated in the first semester. It is the second semester where much of the practical learning occurs, as the students build, debug, redesign, test, collect data, and really evaluate their design, specifications, and approach. Much of their success depends upon skills they are still acquiring: working as a group effectively, tasks estimation, and project management.

1 Mercer University, Mechanical and Industrial Engineering Department, Macon, GA 31207.
Table 1. Senior Capstone Design Project Course Goals

The project goals for the students include:

- Identify and formulate a clear design problem statement.
- Establish objectives and criteria for completing the design project.
- Develop and adhere to a budget.
- Use a wide variety of sources for gathering data.
- Develop alternative designs with specifications.
- Conduct appropriate analysis for determining the best design or approach.
- Develop a written detailed plan for constructing, testing, and evaluating the best design alternative to satisfy client goals.
- Manage the tasks of construction, testing and evaluation of the design.
- Work independently and collectively towards the project goal.
- Learn to improvise and revise designs and plans to meet the project goal.
- Make oral and written presentations discussing problem, recommended design, constructing, testing, and evaluation of the design.

Project Management in Industry

While the purpose of the two-semester capstone design course is a realistic engineering experience, it is understood that an undergraduate design course cannot provide the full experience of an industrial project. In industry, project teams are generally multidisciplinary in nature, often including marketing, finance, design, and other non-engineering disciplines. These teams also include members with a range of experience, from ‘old-timers’ with years of experience to new graduates on their first assignment. In addition, in contrast to a senior capstone design course, the primary (often exclusive) success criteria for an industry design project are to successfully complete the project on time and within budget.

Still, there are several similarities between the capstone design course and industry projects. In both settings, the team must develop and adhere to a budget, develop detailed plans for accomplishing project goals and objectives, manage resources and tasks, develop design alternatives, and conduct the analyses necessary to select one to pursue. In addition, the teams must work individually and as a team, as well as communicate effectively both internally and with external constituencies.

Success for a professional engineering design team depends on many factors; several key factors are listed in Table 2. Later in this paper these factors will be compared with student success factors observed by the instructor.

Table 2. Professional Engineering Success Factors.

- Communication skills
- Project management
- Intrinsic motivation
- Personal ownership of project
- Technical competence
- Professionalism
- Interpersonal skills
- Effective leadership
- Experience
Project Management in Senior Capstone Design

Multi-Discipline Group Functional Make-up

Group membership as a function of engineering discipline varied, as the groups were the self-selected. Many factors contributed to the make-up including available projects, interests, friendships, and desirability of good students to cluster. Ultimately the type of problem selected formed the basis of disciplines required within a group. Many projects tended to favor a particular engineering discipline; however, most involved several disciplines. The engineering disciplines represented at Mercer University School of Engineering include Biomedical, Computer, Electrical, Environmental, Industrial and Mechanical. Industrial Management students were also included in the teams. Every team had a client, technical advisors, and a manager. Each discipline represented on a project was required to have a faculty member as a technical advisor. The technical advisor along with the instructor ensured that the proposed project has significant technical content for each student. The groups were responsible for their assignment of tasks, schedule, and final product. The course instructor served as manager of the teams.

Most teams (8 of 11, in the most recent course) were formed with a selected project prior to the first day of class. A small number of people (less than 20%) did not a have a project or group at the start. Self-selected project groups ranged from those with a very strong sense of what project they wanted to those who merely wanted to work together.

Role of Instructor

Aside from the usual role as evaluator, the course instructor functioned as an equivalent to a supervisory or strategic manager in industry. This would be similar to a technical manager or engineering director. The focus of the course instructor was on student performance via the project. Performance was measured in terms of the progress of the design, construction, testing, meeting schedule, solving problems and issues that arose in any open-ended design project. Individual contribution and effort of each student and intra-group interaction was also monitored and guided by the instructor.

Strategic decisions were sometimes outlined or forced by the instructor (as is the case with corporate management) when project milestones slipped or when problems were not addressed within the group. Examples included forcing deadlines for specific actions such as purchasing parts, beginning testing, interim and final reports. However, tactical management of the project was still left to the group to decide.

A typical situation of management interventions follows. A group involved with a microprocessor-based control system was behind schedule because of unfamiliarity with a specific microprocessor and prototype board. The instructor (manager) made the suggestion that a more familiar microprocessor might be acceptable to the client if a working prototype could be delivered on schedule with similar function. The students received client approval and proceeded with the new processor in a more productive fashion.

Project Management by Students

As in industrial projects, the students were required to be aware of the project and the delivery schedule. Status reports by individuals and groups were required at set intervals. Students developed a schedule and monitored it as an integral component of their status reports. At least initially there was some reluctance to use Gantt charts for schedule monitoring. Students did not see the schedule as an important document at first. This is similar to many new engineers in industry. However, as work progressed the important role of project management became more apparent. The impact of design changes during fabrication and testing on the schedule was seen as the projects got closer to completion.

Although students had been exposed to concepts of project management during previous courses and in the first semester of this senior capstone design, project management concepts such as critical path, buffers and scheduling

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of resources were not present in most plans. Most students did not conceive of failure (even on a partial basis). In addition, redesign and re-testing tasks did not appear on many initial schedules.

Division of work and individual assignments were typically not included. The whole process of project planning was not necessarily logical.

A fairly modern planning approach taken from industry is that of "Theory of Constraints." [1,2] Here the project schedule is worked backward from the desired result, determining the necessary preceding steps. Students, as well as many professional project managers, start project planning from the beginning step and plan forward, hopefully to the desired end. This sometimes added unnecessary steps and missed parallel paths. Parallel paths were usually required to expedite a project.

**Group Dynamics**

A strong leader was generally found in each successful group. However, it was important each student feel in control of his/her portion of project. The most successful teams took personal ownership of their projects.

In general the three-person groups worked well. Unless the project was exceptionally difficult, four-person teams tended to have too little work to divide equally. The two-person groups were short handed and also did not do as well as the three-person groups. One of the two-person teams became effectively a one-person team and failed in the first semester. Students beginning the course without a pre-selected project generally formed the two person groups. As such they were missing strong leaders. In fact, not having decided upon a project by the first day of class, was an indicator of weak leadership on a team.

The use of different projects for each group allowed the groups constituents to vary to match the project. Competition between groups was present, but it was not as strong as in courses where multiple groups tackle a single problem. (A competition-based senior project is found in reference [3].) Still, students were initially reluctant to seek help from other groups. Self-reliance, perceived competition, and not wanting to add work to other students were factors in the students' decision to seek help from other groups as a last option. As an example, although a few students had significantly more experience interfacing and programming a microprocessor used in several designs, they were not asked to provide assistance by individuals in other groups. However, the students were later encouraged, by the instructor, to offer and seek assistance across groups. In industry, company experts are actively sought out to expedite projects. This is typical of most work-place environments, where functional groups or projects groups assist one another for the common good of the organization. This is one of the first changes that occur as engineering students transform into engineers.

Team peer pressure was very prevalent in the resulting performance of the groups. Most group members exhibited a strong loyalty to their group, which helped the group see the project through to completion. On the extreme, a student briefly considered withdrawing from the course when he indicated his efforts were not up to par with his team members. (In this case, the student discussed withdrawing with the manager/instructor. He was persuaded to finish by advising him that the lack of his contribution, regardless of the extent, would most likely hurt the project and his group. The instructor noted that the grade received could be less than that of his peers, dependent upon his and the group's total efforts. The student's work ethic improved and his contribution to the project was nearly equal to his peers.)

**Observations of Student Success**

While many predictable factors can be stated about a project's success, some less apparent factors were also noted. Although student interest in the project had a lot to do with the initial selection of the project, student success had more to do with other factors such as personal ownership or project, work habits, and good planning. The main student success factors, as noticed by the instructor, are listed in Table 3.

Project management factors were of primary importance in successful groups. Many people simply did not budget enough time to do everything they planned in the second semester. While virtually all groups indicated they
intended to start work on their projects in the time between the two semester courses, only one group did anything and it was very little. It was difficult for groups to be truly objective regarding approach, work, and project requirements. Communication within the group was important. Each member needed to be working with updated information towards a common goal. This clarified the project tasks and interfaces between people, especially as the design evolved during construction and testing.

Aside from time management of the project, other decision factors greatly affected the results. Determination of a critical few issues early in the project was important. Early testing of unknowns led to design changes and a smoother project. Typical project unknowns included items such as special features of electronic components, software compatibility, and process data availability. Groups that allowed for failure and redesign had less difficulty in completing their projects on schedule.

As mentioned earlier, two-person teams tended to do significantly worse than teams with three people. The additional person was important in less motivated and weaker teams, as assistance could be rendered within the group. (Future courses will strongly discourage two-person teams.)

Table 3. Student Success Factors.

- Drive/ambition
- Personal ownership of project
- Work habits/Time commitments
- Group peer pressure
- Number of team members
- Language skills
- Interpersonal skills
- Management of project
  - Critical path planning/early testing
  - Task assignments
  - Communication within the group

Project Types

As outlined in the introduction, projects were available from various sources. Available clients included local industry, private individuals, government agencies, and faculty. Students were encouraged to select external clients to provide the most realistic projects. However, based on familiarity and access students tended to favor faculty clients. Many industrial clients also required a minimum time on-site each week.

Projects with industrial clients typically were of a different design nature than those from other clients. The industrial clients were usually process improvement design projects. While these problems tended to be have significant industrial engineering content, process improvement is important to all branches of engineering. Solutions involved more than one technical discipline. For example, defects in a finishing process line required the electrical engineer in the group to design and program a defect-sensing system, interfaced to computer-based tracking and display.

External projects can have more complications as industrial clients can change employment or corporate positions during the two-semester course. Traveling to the site as well as scheduling work and meeting times with an industrial client is also more time consuming than in projects where the client is on campus. However, there were significant benefits to an industrial client. While the primary benefit was a real industrial project, students were exposed to new tools they may not have been familiar with from the classroom. For example, several groups were required by industrial clients to use the six-sigma approach [4,5] in their project. This provided some additional learning opportunities for the students in these groups. In several projects with industrial clients the students were invited to apply for fulltime engineering positions.
Comparison of Student and Professional Engineering Projects

Table 4 provides a comparison of the success factors for student and professional design teams. As might be expected, there are many similarities, as well as factors leading to professional success that can be traced to earlier student success factors. For example, the ‘drive and ambition’ that lead to student success might later be seen as the ‘intrinsic and extrinsic motivation’ that help a professional to succeed. Similarly, the ability to effectively handle ‘work habits and time commitments’ as a student might later become a sense of ‘professionalism’ for an engineer.

Table 4. Comparison of Industry and Student Success Factors.

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<th>Student Characteristics</th>
<th>Professional Employee Characteristics</th>
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Task assignments within student groups deviated from typical professional engineering groups. For example, one group implemented a multiple path approach in the programming phase of their project. Here all students in the group were working on the programming of a microprocessor in parallel. The first successful approach was adopted. This might at first be considered outrageous as effective time management in industry, but this was a critical path item (although they may not have stated so explicitly). So rather than assign the task to one person, the entire group resources were used to accomplish a particular task. This is similar to the Theory of Constraints approaches to project management used in manufacturing and product development of many industries. Also, it was important to each of the students in a group that they learn a new technology (e.g., programming a new CPU) while completing the project.

Schedule updates were required bi-weekly by the instructor (manager). The students spent little time really planning and managing their projects, relative to professionally managed projects. At first the students saw the Gantt charts of the project schedule as an additional burden, not a tool to help them monitor progress and make decisions. The value of alternate paths and designs became apparent, as the students progressed through their projects. Project management, as a tool, became more evident as the final Critical Design Review approached. Schedule driven, timely completion of the projects was emphasized.

Similar to many industrial projects, time management was always not well thought out. Make vs. buy decisions often were revised when time and effort were considered. For example, a group of electrical engineers originally planned to fabricate enclosures from sheet metal. As construction and programming became more critical, the students chose to purchase inexpensive enclosures. This allowed them to focus on their areas of expertise and competence. Emphasizing core competence was another important industry concept learned, by the students. Realizing resources and experience limitations was essential to successful time management.

Loyalty and responsibility to the group were a positive team building trait of the student projects that are analogous to the professional work environment. The efforts of the individuals were generally self-regulated within the group.
Individual contribution as well as team efforts were rewarded in the classroom. As in industry not all members of a project receive the same reward.

Summary

While course work is different from actual engineering work, the experience of a capstone design helps prepare students for professional practice of engineering. There are many similar behaviors of engineering students to practicing engineers. Of all the team skills gained from the project experience, the most valuable ones gained from an industry perspective are project management, group social dynamics, and the ability to see a project to completion.

References


Hodge Jenkins

Hodge Jenkins is currently an assistant professor of Mechanical Engineering at Mercer University, School of Engineering, beginning in the Fall of 2002. Dr. Jenkins has nearly two decades of professional engineering design and development experience. He has worked most recently in optical fiber product development since 1996, with Lucent Technologies, Bell Laboratories after graduating with a Ph.D. in Mechanical Engineering from Georgia Tech. The author also holds both BSME (1981) and MSME (1985) degrees from the University of Pittsburgh, and is a registered Professional Engineer.

Laura Moody

Laura Moody is an associate professor of Industrial Engineering in the Mechanical and Industrial Engineering department at Mercer University. Prior to leaving Mercer to spend 3 years as the manager of the North American Usability Group for Whirlpool Corporation, Dr. Moody taught for 12 years in Mercer’s School of Engineering. There she taught a variety of courses at the graduate and undergraduate levels and was for two years the chair of the Department of Industrial and Systems Engineering. She holds the Bachelor of Electrical Engineering degree, MS (Human Factors Engineering), and Ph.D. (Human-Machine Systems Engineering) degrees, all from the Georgia Institute of Technology.