A Unique Capstone Design Program

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Abstract

This paper describes a capstone design program which has been developed at Oklahoma State University over the last ten years. The key components which have contributed to the success of the program and those which make the program unique are detailed.

Introduction

We feel that the capstone design course is the most important course in our undergraduate curriculum. To understand why it is so important, consider the characteristics of typical undergraduate courses. Most courses, by necessity, focus on a narrow technical subject (e.g., electronics, electromagnetic, communications). Homework assignments generally ask specific technical questions, which have one solution, and which only take from a few minutes to an hour to solve. If students are not able to answer a problem in that length of time, they move on to other problems, since they usually have many problems to solve. They never get a chance to learn that some problems take weeks to solve, and they never develop the confidence that if they spend the time, they can solve the problem. Any term projects which are given in typical classes are usually very limited in scope, and each student generally works on their own.

This is not to say that these other courses are bad. By necessity, we often need to focus on specific technical subjects in most courses, in order to expose students to the rapidly expanding body of knowledge in our discipline. However, we need to have a course which ties everything together, and prepares students to solve real-world problems, which are ill-defined, interdisciplinary and open-ended.

In contrast with these typical courses, consider the capstone design course. Some of the things which students learn in this course, which they don't learn to the same degree in any other course, are to:

- Work independently.
- Be creative and show initiative.
- Cooperate with other members of a team to achieve a joint goal.
- Communicate orally and in writing.
- Organize large projects (learn to subdivide large problems and schedule subtasks).
- Manage time.
- Work within a budget.
- Follow directions of a supervisor.
- Locate/order parts.
- Anticipate and adapt to unexpected difficulties.
- Draw on knowledge obtained in many other courses, and adapt ideas to new situations.
- Operate under time and performance pressures.

Most capstone design courses achieve only a few of these desired results. In order for students to learn all of these important skills, the course must have certain characteristics, First, the projects must involve real-world problems; they must be challenging but doable. Second, the projects need to be organized into teams, with good supervision and guidance for each team. Third, and most importantly, there must be a firm performance requirement. Unless the students are aware that performance, and not just effort (which is difficult, if not impossible, to quantify), will be the measure of their work, they will often stop short of that extra push that can lead to a successful project. The students need to be given an opportunity, and the encouragement, to succeed. They will live up to our expectations, and their success will breed a confidence, which will lead to future successes.

The remainder of this paper will describe our capstone design course. We will describe how the various components of the course have evolved to meet our objectives. The development of this course has been an on-going project for the last ten years, and we expect that the course will continue to evolve for the next ten years, as we continue to learn from our students.

Before we discuss the capstone design course, we should explain that it is usually taken in the final semester of the senior year. It follows a preliminary one-semester course which addresses basic skills (debugging, wire wrapping, project planning, small project construction etc.). By off loading some of the educational requirements into the first course, the main project can be assigned sooner in the final semester.

The main objectives of the capstone design course are to teach students how to work in teams and to successfully design, construct and document a complex system. Each team (typically four students) is assigned a project and a mentor during the first week of class. On the twelfth week the system is expected to be working. If the system is not working each team member suffers a reduction of a letter grade.

Course Structure

A primary challenge in conducting a program of this type is to have a constant stream of challenging yet manageable projects for the teams to undertake. Coming up with challenging problems is not difficult for our faculty. What is difficult is obtaining funding. Not only are projects expensive to build, but maintaining the lab is also a concern. Industry is a logical choice for both funding and project ideas. The problem is often one of convincing industry that our students are capable of producing professional quality results. Since our projects are typically very expensive to build, often requiring thousands of dollars each, it is essential that the quality of our work be high. Industrial funding is used to buy parts for the project, cover transportation and other costs, and to keep the lab well equipped and up-to-date. The task of attracting industrial sponsors is a year-round effort for the course coordinator.

The main course requirements are: the project must work, it must meet the indicated specifications, and it must be fully documented. At the end of the project each team is required to make an oral presentation of the project to a general audience. The systems we build usually involve some combination of software and hardware design. The design of these systems requires many distinct steps, some of which are:

- Understanding the problem
- Developing solutions
- Defining project subtasks
- Time management and work breakdown
- Subsystem construction
- System integration
- Testing
- Documentation

Although the above items seem obvious, successful execution of such a plan is the real challenge. New and unexpected difficulties always arise. Knowing how to deal with the unexpected makes the difference between success and failure. The inexperienced student often has difficulty estimating how much work is required to complete a project. "If the system is designed then we are almost done." This common misconception has led to teaching the 50/90 Rule. Simply stated, this rule says "When you are sure that your project is 90% complete, then you are halfway there." This is true because the more subtle problems don't manifest themselves until the system is being assembled in final form. What at first seems like a "noise problem" may in reality be a major design flaw. A "small software bug" is often a faulty algorithm. These problems can only be overcome if proper planning allowed sufficient time to be devoted to their solution.

In the early days of the program some projects worked and the rest came "very close". Very close was usually not close at all. With better understanding of the 50/90 Rule, we improved our ability to predict which projects would be completed successfully. It took several semesters for the concept to be believed and accepted by the students and even some of our skeptical faculty.

A key to the success of our program has been the ability to motivate students to begin intensive work during the first week of the semester and to continue that effort throughout the project. The emphasis on the 50/90 Rule has contributed to this success.

A major problem that we were faced within the early days of the program was the conflict that students had between getting the project completed and studying for final exams in other courses. To alleviate this problem we moved back the project due-date from the end of week #16 (pre-finals week) to the end of week #12. After threats of riot subsided, we were pleasantly surprised to find that the problems this change caused were small in comparison to the benefits reaped. The reduced time is not a real problem if project selection is appropriate, proper time management is applied and the project and team assignments are given during the first week of class. This change had the additional benefit that those who believed they were "almost there" and could be done in "one more week" (after the twelve weeks were up), could in fact be given the time. It became painfully clear to many that in reality they were not nearly so close. These instances helped sell the 50/90 Rule to incoming students. As the concept was accepted, the success rate increased.

Mentors

The mentors are a very important part of the formula for success. They are assigned to the teams to act as managers. They meet with the team on a weekly basis and interact with the instructor, who ultimately assigns all the grades. Mentors provide time management guidelines and occasionally technical advice. The most effective mentors are those who understand the problem-solving process and can convey good time-management and communication skills. They encourage and stimulate the students to be excited about the project. Mentors also provide focus, critique, praise and other feedback to assist the students in any way possible. In the early days, mentors were thought of as technical consultants. This made it difficult to find mentors to match the projects. Another drawback of this role for mentors was that students often used it as a crutch. "If the mentor doesn't have the answer, how can you expect me to come up with one?". It became clear, however, that students were strong technically but weak in planning and time management skills. This led the mentors to take on a more managerial role. The mentors and instructor meet biweekly so that all are kept up to date of project progress. This interaction ensures that the demands made on the teams areas equal as possible. Successes of the past have helped to steadily improve the quality of the projects. The mentoring experience has also helped our faculty to better see the technical competence and professionalism of our students.

Problem Description

The problems submitted to the student teams are often very "fuzzy". This is partly because that is the way that most problems originate in industry. It is also a way of getting the teams to think about the problem, come up with some ideas of their own and better identify the real problem. They often find that an accurate definition of the problem can be the most difficult part of the design process. The brainstorming session that is

required to define the problem encourages teamwork and puts the team in a problem solving mode. Students often come up with excellent original solutions, if they are encouraged to take time to think about them. A requirement of our capstone design program is that multiple solutions be considered before a final design decision is made. Reducing choices and making selections is an exercise which helps develop better judgment and produces more effective solutions.

Final specifications of the system are agreed upon, signed by all parties involved and submitted to the instructor. In the early days, specifications were given at the beginning of the semester with the project assignment. This seemed to reduce the options for the students and led them to "design" before they took time to really think about the problem. Some projects, by nature, have "rigid specs" and these are still given early. For most projects, a preliminary specification is developed during the second week of the semester, but is then updated later. Even the most "rigid" of projects have room for options that allow the students more freedom, and get them more excited about working on the project.

Milestone Charts

Not surprisingly, most student teams do not adequately understand project planning; this is not adequately addressed anywhere else in our curriculum. They have little idea how to subdivide a project, how to determine what the important/difficult points are, or how to decide how long each subtask should take. An accurate milestone chart is essential for a successful project. The instructor, lab assistants and mentors provide invaluable assistance to the teams in developing a milestone chart. We set no rigid format for milestone charts; we only require that they be well thought-out and represent a reasonable path to success. These charts are prepared during the second and third weeks of the semester.

Bi-weekly oral and written progress reports

To help ensure success, the milestone chart is referred to in the biweekly oral and written progress reports. One member of each team makes a brief oral presentation of the team progress. This gives each member the opportunity to make at least one oral presentation. The oral presentation is accompanied by a written report which documents the progress of each team. These are primarily used to keep the teams on schedule and inform the other teams of each project's progress to date. Successful, hard-working teams have a positive effect on the performance of teams who may at first be lagging behind.

Design Defense

To ensure that the teams are going to build a working system, each team must be subjected to a "design defense." This is a way of setting a deadline for the design by putting closure on the design phase. It also ensures that the design is feasible. The teams are asked "tough" questions that they must answer "on their feet." This exercise is necessary to ensure that their design is feasible and that they understand how to proceed. Before the design defense was incorporated in the program, the design phase for some teams continued indefinitely. Without closure to the design phase, teams floundered and projects were prone to fail.

Mid-Term Presentation

The more intermediate deadlines we set, the easier it is for students to successfully meet their goals. The Mid-Term presentation deadline encourages the teams to focus on the 50/90 rule. At Mid-Term the project should be almost complete (in the opinion of the students), but will usually have some "bug." This presentation usually exposes flaws which require some redesign. Since the flaws are discovered early, there is time to take the appropriate steps to save the project.

Final Presentation

At the end of the project, each team is required to give an oral presentation. The final system, no matter how complex, must be made understandable to a general audience. Oral communication is a very important skill that is often underestimated. It is essential for an engineer to be able to convey concepts in easily understandable terms, even when communicating with a general audience. To assist us in this area we have worked with the English and Speech Departments. Their assistance to us in the area of public speaking and collaborative writing has helped both our departments. Speech students prepare presentations to our class as part of a practicum. This gives them practical experience in teaching speaking skills. It also helps them learn what engineers do. Our students reap the benefit of their lessons. This collaboration has been very helpful in preparing our students for public presentations. The presentations, which are aimed at a general audience, help publicize our program and the lab's capabilities. It is also a vehicle where proud parents can see that their tuition money did not go to waste.

During the first few years of the capstone design course presentations were made by all the teams in a classroom which seated 120 people. Presentations were, and continue to be, 30 minutes each. During the presentation the team members describe the project, explain its function, demonstrate it in action, and answer questions from the audience. With as many as 10 projects in a semester, presentations at times became marathons. When a few poor presentations were added to the mix, the resulting experience could be truly painful for the audience. With the assistance of the speech department, the presentations have now improved to the point where even the worst ones are pretty good, but it is still unreasonable to expect a large audience to sit through ten presentations of 30 minutes each.

We continue to have Final Presentations, where every team presents, but we now select only the best four teams to give their presentations again at the Awards Presentations, which take place one week later. The Final Presentations, which we no longer publicize externally, have become a preliminary competition, which ensures that the oral presentations are of the highest quality.

Awards Presentation

The Awards Presentations came about as a result of the problem with presenting a large number of projects to a large general audience. We now have only the four most interesting and highest quality presentations given at the Awards Presentations, which has a general audience of 300-400 students, faculty, industrial representatives and parents. In addition to producing a shorter and more entertaining program, we also found that this new selection process produced a new level of competition among the teams. This led to improved quality in workmanship and communications skills across all of the teams.

In order to try and maximize the quality of the presentations we invite respected members of our community to act as judges at the Awards Presentations. These include faculty members, industrial executives, attorneys, doctors, English professors and others. Judges from outside of our department are especially helpful. Because they are not familiar with engineering jargon, they can let us know how well we communicate to the general audience. These judges often make excellent suggestions for improvements to the course. Several projects have been suggested by executives attending our presentations. The judges have been consistently impressed with the communications skills, quality of work and maturity of our engineers.

Poster Session

On several occasions there have been more than four excellent projects in a given semester. Originally these extra teams were completely left out of the Awards Presentations. We now organize a concurrent Poster Session, at which all of the remaining teams create displays which illustrate their projects. This allows interested parties to inquire about the project and to see demonstrations of all the projects. All of the students get a chance to participate in this major departmental conference.

Some projects may not have visual appeal. In some cases, students are "camera shy" or there is some reason they do not wish to present before a large audience. The project teams that do poster sessions are given the opportunity to show off their work before the formal presentations and again after. This gives exposure to most of our projects and helps make a better overall presentation. The poster session also serves as an incentive to do a good job, since potential employers will be viewing the work. In the past, those who did not make the "final four" felt left out. Now the "final four" teams are given a choice of whether to present or give a poster. If one of the selected teams opts not to make the presentation, it opens a slot for one of the other teams.

Publicity

In order to maintain a constant flow of project sponsors, publicity is critical. It is an important part of our program to disseminate information on our capabilities to industry and other potential sponsors. We are also happy to share our successes with those wishing to develop similar programs. Each semester we advertise the Awards Presentations by sending flyers and other letters to interested parties throughout the country. For those companies who cannot send representatives to attend the Awards Presentations, we often give presentations at their site. We also disseminate information about the program via newspapers, TV and radio stations. The best method for advertising the program, however, seems to be by word of mouth from our sponsors and others who know of our program first hand.

Documentation

Often underestimated, documentation is one of the most important parts of the project. When the teams deliver the final system, documentation must be accurate and complete. Sponsors have little use for a project which is not well-documented. Documentation is also critical when a project is updated during a succeeding semester. Many projects have relied on the accuracy of the prior team's documentation for enhancements and continued development. The documentation includes text material, schematics, software (source and executable) disks etc. The readability and completeness of the document determines the utility of the system to the sponsor, it also may determine if a project can be enhanced or if a new team must start from scratch. Teams are strongly urged to document throughout the semester and not to wait until after the system is working. The status of the documentation is monitored periodically throughout the semester. The final report is due one week after the Awards Presentations.

Delivery of project to sponsor

The project is complete when the final system is delivered to the sponsor. The sponsor is asked to sign a letter indicating that the system has been accepted in its present form. If the quality of the project is below our standards, we may extend it for another semester without additional charge to the sponsor. Before this letter was made a part of the program, there were occasional misunderstandings as to whether the project was satisfactorily completed. On one occasion a sponsor called weeks after the end of the semester requesting hardware that the students claimed to have delivered (but did not). Keeping all things well-documented is the best way to operate.

Conclusions

Over the past ten years we have developed a very successful capstone design program. The key to the success of the program has been a firm performance requirement. When students are aware that performance will be the measure of their work, they will make that extra push which can lead to a successful project. The experience of success, when presented with a difficult challenge, breeds a confidence that remains with the student long after most of the specific technical knowledge which they have acquired in other courses has been forgotten.