Development of the Capstone Design Experience in a Rural, Regional University

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Abstract

The challenge of providing a design experience for senior engineering students is complex for every university, but the difficulties are only intensified in smaller regional universities that are located in more rural areas. This paper will explain the development of the capstone design course at Murray State University. Various goals are sought in the capstone design experience. These include teamwork, communication skills, creativity, development of a working prototype, work with research faculty, competitiveness in a design competition, and the ability to work with industrial sponsors. In this course we have tried several alternative methods for providing the design experience. Relative merits and demerits of these approaches are discussed in this paper.

Introduction

Design education is an important part of the engineering curriculum in any engineering program. Indeed it is the design aspect of engineering that most clearly separates engineering as a distinct field from the sciences (Simon, 1981). In learning design, the student uses a wider variety of mental skills to develop solutions to problems. In most of their courses the students translate a problem into a known model and then use standard methods to reach a common, often numeric, solution to the problem. In design courses students are forced to ask questions that go beyond the commonly accepted models of problem solution. Design students must learn how to define the problem, develop their solution space, envision possible approaches, develop testing methods, synthesize results, and judge between alternative solutions. Because of the centrality of design to the engineering curriculum, considerable thought must go into the development of these higher level intellectual skills.

In providing this education to prospective engineers, there are likely to be as many approaches as there are programs. The goal of most programs is to incorporate aspects of design in all areas of their curriculum. This is typically accomplished by adding projects or more extensive problems to those typically assigned in engineering science courses. Many programs have a course dedicated to specific areas of design such as machine design or thermal system design. This allows students to develop their design skills in an environment that focuses on a specific area of concentration. This concentrated effort is then applied more generally in a senior capstone design course. In the capstone course students are given more freedom to consider the broader implications of product design. This curriculum works well in large schools with

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broadly diversified offerings in the engineering disciplines, but does not necessarily fit the needs of small, relatively new programs in regional universities.

The engineering program at Murray State University (MSU) consists of one ABET-accredited program resident in one department within the College of Science, Engineering and Technology. There are no graduate engineering programs or Ph.D. degrees offered at MSU. A small faculty composed of both physicists and engineers teach all of the classes in addition to general education classes. The accredited program is an Engineering Physics program that existed for two decades and was modified four years ago to meet requirements for accreditation by ABET. The program provides a general engineering base of mechanical and electrical courses with some advanced work in modern physics. Even before accreditation the program was quite successful in finding employment for its graduates in a broad range of engineering positions. Companies hiring graduates are typically in the computer, defense and aerospace industries. Students desiring co-op experience have also found employment in a variety of industries and national laboratories. The university is approximately two hours from the nearest major city and has no substantial industrial base.

The program at MSU has sought to incorporate design throughout the curriculum. Although the capstone course is a major part of the design experience at MSU, the groundwork for the course is developed by challenging the students with design problems and projects in the engineering science courses (Cobb, *et al.*,2000). About half of the engineering science courses require students to complete a design project in the context of the coursework and the other half include open-ended design problems in the assignments. From these experiences students gain not only a basic set of problem solving skills but also the understanding that analytical problem solving is only a part of the overall design solution. Students also take an Introduction to Design course, which is the first course entirely devoted to the design process. In this course students are exposed to topics such as design problem formulation, statistical testing methods, design of experiments, optimization techniques, economic analysis and marketing. In this course student perform two small design projects as teams. From this experience students see that there are different ways of meeting design objectives and are challenged to evaluate the products developed by the other students. By including design aspects throughout the curriculum this program parallels what is done at many larger universities. However, significant challenges face the small rural engineering program in providing a more involved capstone design experience for their students.

Challenges Facing Smaller Rural Programs

There are several impediments to the development of a capstone design experience at MSU. The lack of college of engineering resources, limitations on faculty research, lack of local industrial design effort and program generality pose serious challenges to giving students the experience they will need as engineers involved in the discipline and art of design. In the context of delivering an education two phrases that might seem to apply are “location, location, location” and “size does matter”. While some of these differences should be addressed directly, some of these challenges are just the nature of the beast and will always exist as limitations of the program. Small universities also have inherent advantages, such as close student-faculty interaction, flexibility, low costs and fewer distractions that can be beneficial in the context of teaching students the art of design.

The teaching environment of the small rural university is significantly different than that of the major research university, and the differences have an impact on how the capstone design course is taught. A major difference is in faculty responsibilities. In the MSU program faculty members are typically involved in teaching three or possibly four courses during the semester and also are expected to be active in research. The research is naturally limited due to lack of time and graduate students. The time for student interaction with faculty may actually be greater due to the undergraduate focus, however. Although funding which accompanies the research effort can be an issue, the more important limitation is the lack of facilities and the breadth of specialization that are inherent in the research university program. At research universities the design course can be an extension of the research effort of the faculty. In addition to the load on the faculty there are some logistic differences between the two types of programs. For example the supplies that may be obtained for students to build prototypes is more limited because of the lack of university central stores facilities and dependence on either catalog suppliers or local hardware stores. Also there is less understanding at the college level of the importance of the capstone design course since the faculty consists primarily of non-engineers.

Involving industry in the capstone design projects is another barrier that must be faced by smaller rural universities. At MSU there are a handful of local companies that are located in town and a few others within an hour's drive that could provide a natural link to the real world for the design course. These industries are generally focused on production line management and have limited personnel with design experience as relates to the product. They have talented people to help students see the importance of manufacturability and design of production equipment, and they have been used to a greater extent by the MSU technology program. Because of the limited number of industries in the region, student interests do not always match available projects. Some of the difficulties of working with an industrial sponsor are not unique to small programs, but still need to be considered. These include a more complex working arrangement, difficulties in coordinating meetings, and the time restrictions that may be imposed by the sponsor. The advantages of working with industry are also significant and should be considered. Real-world experience, contact with experts, completeness of assessment, possibilities for ongoing projects and availability of funds and facilities are features that make working with an industrial sponsor a very attractive opportunity, even if the choices are limited.

Program generality is also a concern for small programs. The Engineering Physics program at MSU is a fairly general curriculum involving a mechanical and electrical engineering base, along with some added emphasis in modern physics. The general nature of the program is advantageous in appealing to regional students with broad interests, in providing flexibility in the curriculum and in giving students a good fundamental background. The drawback for design is that there is less certainty in the knowledge base of the incoming design students for any given year. The program's flexibility allows students to start the two-course sequence without necessarily having completed Circuits, Mechanics of Materials, or Fluid Mechanics. This restricts the nature of design projects that can be reasonably assigned to the students. Another drawback is that students often do not have room in their curriculum to include a CAD course. This can also be restrictive for design projects that are spatially complex. There is also no area-specific required course that teaches details such as might be considered in a machine design or aircraft performance course. So the possibilities for design projects cover a broad range of application but mostly with simpler products.

Evolution of the Capstone Design Course for Startup Programs

With the development of the world's technological revolution, many smaller regional schools are seeking to add an engineering alternative to their existing liberal arts curriculum. The creation of a capstone design course is fundamental to the development of a program that can be accredited. There are many paths that this can take depending on the speed at which the program is to be developed, the funding of the startup program, and other more political issues. At MSU the course has evolved over four years in slightly differing forms. Lessons continue to be learned and applied to the program. This effort is to some extent a trial and error approach to course development, but was necessary to achieve the appropriate fit with the program's particular situation.

Senior Engineering Design I and II is the two-semester sequence capstone design course for senior Engineering Physics majors. In this course students are tasked with designing an original product or process using the knowledge they have gained during their four years in the Engineering Physics curriculum. In addition to the student projects, many topics are discussed in class to supplement the development of design and testing methods, provide career perspective, and to develop communication skills. Topics include a six-class sequence on written communication, a series of classes on engineering drawing, and classes and discussions on career development, licensing, creativity, intellectual property, ethics, reliability, maintainability, and quality control. Although there is now substantial teaching content in the course, it did not begin this way. Several alternative methods have been tried. Some of these alternatives include completely individual design projects, small teams working on very limited budgets, group projects with industrial sponsors and a project done in the context of an educational grant. This variety of approaches allows for an interesting comparison of methods. These methods will be discussed chronologically as they were undertaken.

Independent Study Projects

During the year before the program went up for accreditation the Senior Design Project course existed basically as it had in the previous non-accredited curriculum as an independent study course. Students worked with a faculty member to develop a two-semester design project. The faculty member acted as a mentor on the project and provided input as needed to the student. The course to some extent paralleled the senior research project course in the Physics major. This process worked fairly well when the student numbers were small. If a faculty member had more than a few students assigned to him, however, involvement would necessarily be more limited. There was essentially no formal instruction given to the class. The class would keep the course instructor advised on their progress at intervals of about two weeks. Students were required to produce a formal proposal at the end of the first semester and give written and oral reports at the end of the second semester.

Projects chosen using this approach were quite varied in their objectives and involvement. Projects were typically chosen by the students to deepen the knowledge they had gained at some point in the academic experience. Two of the students had put together an environmental emphasis in their programs. One student worked with a professor in the environmental technology program on developing a wastewater remediation plan for an Air Force base. This worked out well because of the involvement of the professor in the project and the availability of plans. If there was a down side to this project it was that the student did not gain experience in conducting a test plan or in creating a product. (The student also ended up going into medical school and may have actually had more use for another type of project.) The second student had a project that would modify a plan at a plant that created gypsum as a byproduct. After several months, however, the company decided to abandon the effort and the student's project became essentially a business analysis of the best ways to dispose of gypsum. These were the last environmental engineering projects attempted, and were completed just prior to accreditation. The Environment Engineering Technology program at MSU has continued to grow and plans are underway to develop a full-fledged Environmental Engineering program at MSU. These projects do show the value of a good mentoring relationship with faculty, as well as the risks involved in working with projects in industry.

Another source that was useful in finding projects was the extension of work done by students during co-op and work experiences. One student during this time continued some work in using computation fluid mechanics to explore two-dimensional flows. The student had spent a summer at Los Alamos National Laboratory and made some good contacts, which he was able to maintain during his senior design project. A problem with this type of effort is that it is primarily analytical in scope. It is questionable as to whether writing a computer code really gives the student a real sense of evaluating design alternatives. Another student had worked with a company that provided him with some extensive experience in landfill design. He was able to come up with a plan to design a landfill for a local county during the first semester of the project. Since there was no real relationship to a sponsor there was little more for him to do during the second semester. The student desired to start a more tangible project and did a nice job putting together a cantilever vibration apparatus for a lab and instrumenting it with a Hall Effect circuit to measure vibrations. The positive aspect about this method can be seen in this flexibility to change projects mid-stream. The student was able to put together a design on paper for the first project and actually get to build and test a second project. Since the MSU Engineering Physics program has been relatively successful to date in placing students in good co-op positions it is likely that the use of these contacts will be continued in the capstone course as they are available.

Industrial Group Projects

Two of the objectives in the MSU program are to give our students a real world engineering experience and to help them to appreciate team dynamics in engineering. The significance of institutional-industry interaction has been well documented in the literature (Dunn-Rankine, *et al*. 1999). One thing done to focus on these objectives was to develop a relationship with a local Briggs and Stratton engine manufacturing plant to provide project work for senior design projects. Plant management was very cooperative and eventually came up with a pretty extensive list of processes to investigate. The four students were eventually assigned to design two modifications to two of the plant's transfer stations. The difficulty in this project was in defining the project and getting the students started. Because it took a while to develop the industrial contacts and to work out meeting times between the students and plant supervisors, the project was not decided upon until after the middle of the first semester. It also became evident that although the group had not expressed a preference for any particular type of design project, it was clearly not in the area of manufacturing engineering. Only one of the four students was a strong initiator and he ended up doing most of the work. The project was not particularly successful in providing the group with a positive teamwork experience. Although they did develop a prototype for key parts of the two systems, the final product design was completed at the last minute and no feedback was gained from the plant managers. This type of project could be attempted again, but care must be taken to pre-plan the project to get a reasonable start, and to do this when the students initiate a desire to work with industry.

Another group began a similar project the following semester that was somewhat more successful. The group of three students was completely different in temperament and motivation. One of the three students had been previously employed by Lodestar Energy Company and initiated an idea to solve a real problem the company was facing. The system they designed would de-water an abandoned mine shaft that was getting close to breaching seals with operational mines. The three students all shared an interest in the project and took on roles within their team. They developed their own schedule and followed it fairly closely. Their product included three alternatives for a system of pumps and pipelines that would optimize the process for cost. The final plan was presented to the company and was considered in their decision. This plan did not allow for testing or actual construction so the students received relatively little feedback as to whether their design would actually work. It also resulted in some overall specifications but no detailed design work. Overall the project was viewed as successful in regards to the teamwork and the involvement with industry.

Two Person Small-Scale Projects

The next phase of the evolution of the capstone course was to encourage pairs of students to work on small-scale projects that could be done at reasonable cost and allow the students to build either a physical prototype or proof-of-concept model. Several lessons were drawn from the previous two approaches to the design course and these resulted in prioritized criteria for choosing design projects. Since the project lasted two complete semesters it was imperative that the projects were selected judiciously. Students were provided a list of around 100 ideas pulled from various databases, texts, (Ertas and Jones, 1996) and web sites in the spring before they started the course. In this way students started to work on their projects almost immediately when classes began in the fall. At this time the scheduling was also changed such that the sequence must be started in the fall except for rare exceptions. This allowed for improved planning of projects and reduced faculty effort needed to manage the course.

Under this approach the criteria for projects were:

1) Feasibility. Is it physically realizable and can it be done with the available resources in the allowed time?

2) Interest to students. The student's motivation is the most important factor in determining the outcome of the project.

3) Working prototype. Projects in which students develop some of the design on an experimental basis are preferred. They are expected to actually build something, which may include prototypes, mock-ups, partial system tests and proofs-of-concept. Projects that have developed working prototypes have given the students a better concept of the difficulties encountered in turning a concept into a real product.

4) Industry interface. Work with local industry is a benefit to the program in that it may provide funding and facility resources, give students access to real world experiences and expertise, and lead to eventual co-ops or employment of students. Care must be taken to ensure that the time frame for project completion is acceptable to the company and that the sponsor will give sufficient design freedom to the students.

5) Faculty research involvement. Projects that would help develop research equipment and methods are encouraged. It must be primarily the student's design, however. The need for open-endedness, as well as resource and time constraints can limit the availability of these experiences.

6) Teamwork. To ensure involvement of all students the standard team size is two. Project proposals for groups of 3 or 4 should specifically delineate the responsibilities of each member. In order to evaluate individual effort each student must submit project notebooks and weekly memos. To provide a true team experience students are assigned to design review teams to evaluate another group's project. These teams meet once during each semester. At these meetings each student provides written input based on his role on the team and then the team assembles a design review report.

7) Socially redeeming features. Projects involving occupational health and safety, help to disabled citizens and environmental improvements are encouraged.

8) Potential use as a laboratory experience. For small programs new lab activities are usually welcomed. Some projects may also have additional aspects that can be continued in following years. This is another reason for students keeping the design notebooks. Student-designed labs may also be a source of pride for students when they become alumni.

Using this approach most of the student work continues to revolve around their project, but additional structure was added to the course as it became clear that some students lacked direction in their projects and some material was otherwise left uncovered in the curriculum. It was at this point that material on communications, teamwork, drawing skills, ethics, intellectual property, reliability and life cycle engineering was added to the course. In addition to the project work, students were also given a common tasking during the first semester to get their feet wet in drawing and budgeting for a project. During this semester students had to design a platform for removing wallpaper and then convert the materials economically into a picnic table. Students presented their designs orally to the rest of the class and the class provided feedback. These mini-projects provided a platform for the class to discuss creativity, drawing technique, and the prioritization of design objectives.

This two-person small-scale approach yielded several interesting projects. One pair of students designed and built a prototype recycling machine for office use (Figure 1). The machine was an attractive wood-encased portable device that included a can crusher and a paper shredder. The students had designs for models that would also incorporate other recycled materials such as glass and plastics. The can crusher was a unique design that was tested for ease of use, cleanliness and reliability. The students actually had three or four orders from friends and relatives that they built after the semester was over. Another project involved developing a window support system (Figure 2) that could be used to perform exterior maintenance on upper story windows without leaving marks on interior or exterior surfaces. The students developed a lightweight, portable design that could be used on a wide variety of windows to support two people to perform maintenance. Due to liability concerns these students did not take any orders on their product, but the end result was actually quite a viable design.

Figure 1. Recycle Machine Project

Figure 2. Window Maintenance Support Project

Groups that included electro-mechanical systems in their project did not achieve the same level of completeness in their prototypes. One pair of students designed a remote door opening system for house doors that could be retrofitted to any door with a single barrel deadbolt lock. The electrical part consisted of an infrared actuator. The main problem this group faced was in developing the gearing mechanism for the bolt actuator. These student had not yet taken mechanics of materials and could obviously been helped if a machine design course was a part of the curriculum. Nevertheless, the students learned what they needed to know, procured the appropriate gearing and linkages, and connected them to a breadboard circuit with the remote. Their working prototype would consistently lock and unlock a door from over fifty feet.

Another pair of students attempted to make a system that would identify vacant parking spaces and provide remote indication to people entering the lot. This group focused too heavily on optical systems and would have had a more complete prototype if they had considered mechanical sensors earlier in the course. They had a small scale model device that did give an indication on a set of LEDs. In this case the students and the instructor took on little more risk than they probably should have since neither of them new much about such a system. The good part about this approach toward design projects is that they do not cost too much, so the risk only involves the level of completeness of the students' final project. Both students subsequently took the Engineering Measurements course and probably would have had a more extensive prototype had they reversed the sequence of these courses.

Design Competition Project

Doing the senior design project in conjunction with a national design competition provides several advantages to the capstone experience. One is that competition gives extra motivation to the students.

Another is that the constraints for the design may be more explicitly described so the students may proceed in a more organized fashion. These programs also provide national visibility for the university.

During the time that student pairs worked on their small group projects, one group of four students decided to work toward designing an experiment for the NASA reduced gravity flight program. In this program students design an experiment and fly with it in a KC-135 that provides 20 to 30 seconds of artificial weightlessness. Although this program is not technically a design competition in the sense that one group wins first prize, it is competitive to get a proposed project approved and it has the same characteristic of national visibility. The project was suggested by the course instructor and involved producing a reduced gravity experiment for dense-phase gas-solid flow hydrodynamics. The students did their best to learn a little about the subject and also to put together a viable proposal for the flight.

Unfortunately the proposal did not get accepted for three reasons. Universities that had previously participated in the program were now sending two and three teams. The result was that the number of entries practically doubled for the particular competition. Additionally, the experiment had to prove that it could withstand loads up to 9 g's without failure. Most designs that were accepted were already constructed prior to submission and could be experimentally tested to 9 g's. For this course the structure could not be built prior to the proposal submission date and the structural analysis did not adequately prove its soundness to the reviewers. Finally, the students were not able to successfully communicate the need for the experiment to be conducted. Had the course instructor written some of the proposal himself this would not have happened, but since the students were doing this for a grade it was felt that they should produce their own document. As it turned out the four students completed the second semester by modifying a laboratory device in the instructor's lab, but they were clearly demoralized.

This type of project does contain some risk when conducted as a part of the Senior Design Project course. A better approach is to form a group of students outside of class to work on this program. Credit for the planning of this project can given as an independent study course. If the proposal is approved then it can be made a part of the capstone course. It is best to have someone with some experience in the program, such as a faculty member who has done NASA research, to help students understand what is required. This can also be accomplished by tying in to successful programs at larger research-oriented universities.

Educational Grant Projects

Currently, the design course has retained some of the same features as it did with the two-person teams, but is working on a project made possible by a National Science Foundation (NSF) Course, Curriculum and Laboratory Improvement grant. The grant provides for equipment to create a Multi-Scale Hydro-mechanical Lab and impacts the program's Fluid Dynamics, Engineering Measurement and Senior Design Project courses. The funding has allowed for procurement of small wind and water tunnels, and also for purchase and development of an instrumented crew (rowing) shell. The main concept is that the students can follow the subjects of fluid mechanics and measurement from the lab scale to the full-scale. For the Senior Design Project course students were given the option to form a team and use the new equipment.

One group of four wanted to do something with the rowing equipment, but did not know what exactly to do. The solution was for them to get together with the crew team coach, who became their customer or sponsor, and discuss possibilities. They eventually decided to create an indoor rowing simulator that will support the crew shell in the university's swimming pool and be used with modified oar blade designs to simulate the forces that exist on a shell underway in the open water. In doing this they help to provide the coach a way to help rowers with technique in the off-season when the lake is ice-covered. So far several good outcomes have come from this. The group has done the best job so far in interacting with the customer to decide the best use of their time for this course. The group chose to restrict membership to the four when two others in the class did not attend the orientation meetings. The group divided responsibilities evenly giving each member specific assignments. Doing the project on campus at the pool also makes it more accessible to the students.

An added benefit is that future groups may be able to modify their design to incorporate different testing procedures and underway testing of rowing technique.

Lessons Learned and Future Development

Lessons Learned

Several important lessons have been learned through the evolution of the capstone design course at MSU. First, student motivation is key. The students have to really like the project they are doing if they are to spend time with it over two semesters. It is best to offer students a restricted set of possibilities and let them make the final choice. Second, considerable care must be exercised in helping students choose projects. Students typically do not have the experience to discern between projects that are too difficult and those that are trivial. It is important to challenge students to think ahead of what they want to do prior to the start of the semester. It is best to have several projects run concurrently. Student groups try to outdo each other and know that they must be competitive if they expect a good grade in the class. Additionally class discussions are better. Groups of two seem to be optimal except for special circumstances. If each student keeps a design notebook that is regularly checked by the instructor it easy to gage individual effort. Expanded teamwork may have to take place in the Introduction to Design course or in engineering science course projects where non-performers cannot ride the on the coat tails of the motivated students. Finally, work with industry partners should be pursued, but students should be given freedom to choose their project in the context of the partnership.

Direction for Future Development

One of the next steps in the program at MSU will be a more detailed assessment of the program by following up with graduates and employers to discern the effectiveness of the design experience. Because the accredited program is relatively new this information is not yet available. This will be a significant effort as the program prepares for accreditation under the ABET 2000 guidelines. Students who find co-op positions will be challenged to bring a potential design project or two back with them. Another attempt may be made to fly in the NASA Reduced Gravity program. Several of the department faculty members hold joint appointments at the University of Kentucky, which has been successful in getting its “Weightless Wildcats” teams into the program. Continued use of the instrumented crew shell, wind tunnel and water tunnel will be made in the context of the NSF project. Finally, design project criteria and project team performance assessment criteria will be more explicitly formalized.

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