Design Project Ideas for a First-Year Engineering Course

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Abstract - **The integration of university-based research into undergraduate engineering programs has for several years been a major focus in engineering education throughout the world. For engineering students, training in research and development has until now been primarily concentrated in the final year of studies. Senior design projects, often called "capstone projects," have become almost universal in engineering programs. These nearly always include application of technical material from one or more engineering courses, but often include research, creative design and development, and the written and visual presentation of results to a professional audience as well. Many engineering students have trouble with these design projects. The trouble is not with the application of learned engineering principles to routine design tasks, but rather with the more "creative" and "open-ended" aspects of these challenges, and with the supplemental skills required to make the overall project a success. Examples of these skills would include evaluation of alternative solutions, integration into a project team, procurement of materials, design of experiments, and oral and written presentation of results. In this paper the author presents a number of ideas for design projects that can be included in a first-year engineering course. These ideas were developed from conducting several design projects for first-year engineering students at Texas A & M University at Galveston. The defining feature of these projects is that they incorporate research and development activities. The author believes that it is both possible and necessary to introduce engineering students to research and development issues very early in their engineering studies, and that projects can be attempted for which the level of technical expertise required do not exceed that of the average incoming university student, but that nevertheless can expose this student to all of the essential elements involved in engineering research and development.**

Index Terms – Creative thinking, Design and build, Research and development, Student teams.

INTRODUCTION

For engineering students, training in research and development has been primarily concentrated in the final year of studies. The rationale for this is that students already have the basic technical competence to accomplish design tasks in their field of study and are thus able to appreciate the application of engineering theory to real-life problems. Senior engineering students typically have a number a options, including "senior design projects" done as a group under supervision of a faculty member, "research projects" which supplement the graduate-level research endeavors of one or more faculty members, or an industrial project undertaken in cooperation with an involved engineering or manufacturing facility.

The main problems that engineering students have in these senior-year projects stem from their lack of preparation for the broad scope of engineering work required of them that includes much more than simply applying information learned in coursework to straightforward design tasks. Areas for which incoming seniors lack preparation include problem scoping, consideration and evaluation of alternative solutions, and gathering of information not readily available from familiar sources. With regard to consideration of alternatives, Newstetter and McCracken have noted that even as final-year projects progress, students tend to focus on just one design and try to make it work [1].

Historically there has been significant discussion about requiring engineering students to perform tasks that mirror those needed in senior projects as early as the first year of engineering studies. Baillie has done an excellent review of work performed before 1998 in a comprehensive literature survey citing 54 different sources [2]. This review includes discussion of the various approaches to teaching an introductory engineering course, and to implementing design and build projects which teach students to work as a team, construct and test a working engineering device, and give and oral and written presentations regarding their projects.

First-year design and build projects have also been implemented in a significant number of engineering curricula. Borrego, Froyd, and Hall have conducted a study on the diffusion of education innovations into the engineering programs of a large number of higher education institutions [3]. The study was framed in terms of ***awareness*** (how many schools are aware of or discussing implementation of a certain innovation) and ***adoption*** (how many schools have actually adopted the innovation in their own curricula). It was found that, among all innovations, the inclusion of a first-year engineering project ranked second for awareness at 92%. Only the inclusion of a senior capstone design project ranked higher at 96%. In terms of actual adoption, the first-year project actually ranked higher, at 65% versus 56% for the senior project. In this category student-active pedagogies ranked highest at 71%.

In this article the author describes an engineering research and development project developed over a period of three academic years (2009-2010 through 2011-2012) for an introductory engineering course at Texas A & M University at Galveston. The project was for a course ENGR 111 Foundations of Engineering I, and involved about 25% of the overall course grade. The foundational assumption of this project was that in addition to emphasizing teamwork, design, and communication, it is both possible and necessary to introduce engineering students to research and development issues very early in their engineering studies. Some of these issues specific to research involve creative brainstorming, evaluation of alternatives in the presence of incomplete information, evaluation of acceptable error and risk, skill in utilizing information from diverse sources, design testing and the iterative processes which ensue when a design does not work as planned, procurement and vendor selection, and designing tests and experiments to give the information desired. The author believes there are many projects for which the level of technical expertise required does not exceed that of the average incoming university student, but that nevertheless can expose this student to all of the essential elements involved in engineering research and development. The sophistication of the projects from a technical standpoint does not parallel those conducted by final-year students, but the nature of the work conducted is fundamentally similar.

BACKGROUND

There is presently one engineering program and one engineering technology program at Texas A & M University at Galveston (TAMUG). Both are accredited by the Accreditation Board for Engineering and Technology. The Engineering Accreditation Commission oversees a Maritime Systems Engineering (MASE) Program, which prepares graduates for careers in offshore, coastal, and structural engineering. The systems-oriented approach focuses on offshore, undersea, and coastal structures. The Technology Accreditation Commission oversees a Marine Engineering Technology (MARR) Program. Within this program, a License Option (LO) complements the functions of the Texas Maritime Academy (TMA) in preparing students for United States Navy, Coast Guard, and Merchant Marine responsibilities, while the Non-license Option (NLO) prepares students for other careers in the marine industry.

The course ENGR 111 Foundations of Engineering I is required by all students in both the MASE and MARR majors. The course can also be selected as an elective by non-engineering majors, including those in Marine Science, Marine Transportation, and Marine Administration. The course is a 2-credit course with a laboratory component, and has the basic objectives described by the following table:

TABLE I
SUMMARY OF ENGR 111 COURSE OBJECTIVES

Awareness
Orientation to engineering profession, social and environmental responsibility, professional ethics, affirmative action and minority issues, women in engineering, global challenges, integration of engineering into the overall structure of society.
Knowledge
Design process, critical thinking, technical writing, computer concepts, dimensions and units, introduction to statics and dynamics, thermodynamics, energy calculations.
Skills
Spreadsheet calculations, mechanical drafting, computer-aided drafting (CAD).

The author was given responsibility for redesigning both classroom and laboratory components of ENGR 111 at the start of the academic year 2009 - 2010. At Texas A & M University in College Station, the course is taught to all engineering majors, and catalog specifications allow a wide variation of requirements tailored to the specific engineering major. At Galveston the opportunity exists to actually form ***inter-disciplinary*** teams consisting of both engineering and engineering technology majors; this is not normally possible in College Station where large sections of ENGR 111 specific to one major are the norm.

Objectives for the project as well as desired learning outcomes for the students were adapted from two previous design projects conducted by the author. These projects are described in detail in a paper presented at the North Central Regional Conference of the American Society for Engineering Education in 2004 [4]. Project objectives for the presently-described TAMUG projects are listed in the table below:

TABLE II
ENGR 111 PROJECT OBJECTIVES

Engineering Orientation
Students will become acquainted with all aspects of the engineering design and implementation process, and will receive a "hands-on" orientation to the types of work required in the engineering profession.
Research and Development Skills
Students will be exposed to the basic activities and skills involved in engineering research and development, and will begin to acquire these skills.

The first objective supports the overall course objective of providing students with an introduction to the engineering profession. It is the second objective that is unusual among first-year projects and addresses some of the educational needs listed above. Desired outcomes based on these objectives were as listed below.

Upon completion of the project, students will be able to:

(1) describe clearly the steps involved in designing a product or a solution to an engineering problem and the additional steps involved in implementing this design,

(2) function effectively on a design team with fellow students in such a way that the ideas and capabilities of the individual team members are combined in an optimum manner,

(3) write a detailed set of engineering specifications for a product or a solution based on input data from a prospective client,

(4) systematically evaluate design alternatives as they relate to these engineering specifications, also taking into consideration factors such as product safety, social and environmental responsibility, and the availability of necessary resources,

(5) procure the materials and equipment necessary to implement the proposed design or solution, by using, in addition to visits to local retailers, information from business registers, trade journals and catalogs, and electronic sources,

(6) prepare a technical proposal recommending a given design or course of action to a prospective client and orally and visually present this proposal,

(7) construct a device based on the selected design and perform on this device preliminary testing, both for normal and off-design conditions, and final testing in the presence of the client, and

(8) prepare a final technical report in a standard engineering format, describing fully all aspects of the project, including device design and implementation, testing results, and principles of device operation.

It is seen that Outcomes (1) and (3) primarily address the first objective, whereas outcomes (4) through (8) address the second. Outcome (2) clearly addresses both objectives.

PROCEDURE

The project was first undertaken during the spring semester of the 2009-2010 academic year. At that time 46 students were enrolled in three separate laboratory sections of the ENGR 111 course but were combined into a single classroom section. Most students were in their first year of engineering studies, but some had sophomore or junior status, usually because of transferring from another institution where a similar course was not offered. Two major decisions were initially made with regard to the fundamental nature of the project:

(1) The project was to be a group project: students were divided into nine design groups, with about 5 – 6 students in each group. Meyers et. al. have recently conducted a study of engineering student reflections on their first year experiences and write, "Further, student-student relationships have been recognized as the largest influence on student satisfaction with several college environments with student-faculty relationships as the second-largest influence" [5]. Bonding with fellow students assigned a common task in one or more courses proved to be a significant factor affecting student satisfaction with their first-year college experience, even more than faculty advising and mentoring, consistent with the earlier findings of other researchers cited by these authors [6] – [8].

(2) The project was to involve the actual building of a working device: for this first semester, the device was a tennis ball catapult, with the Evaluation Day requirement that this catapult fire a tennis ball to hit a garbage can lid at two distances between 10 and 40 feet, selected randomly on Evaluation Day. This was a departure from previous projects in ENGR 111, which involved designing a device, but not building it. The requirement for the actual construction of a working device was not only necessary to meet the procurement and experimental design and testing outcomes mentioned above, but also instrumental in aiding student self-efficacy beliefs as the students experience tangible success based on their own knowledge and efforts. This type of success is listed as the single most important factor affecting student self-efficacy beliefs in a study conducted by Hutchison et. al. [9], and also as a factor strongly effecting overall student learning and retention in a study by Cai and Zhao [10]. Another interesting point: team bonding as discussed earlier was also found to be an important factor in both studies (Cai and Zhao list this component as "participate effectively in small teams").

In subsequent semesters, several other devices with varied Evaluation Day requirements were also featured. A summary of these are listed in Table III below:

TABLE III
SELECTED ENGR 111 PROJECT DEVICES AND REQUIREMENTS

Device	Requirements
Tennis Ball Catapult	Hit a garbage can lid three times at each of two randomly selected distances between 10 and 40 feet.
Mid-air Collider	Two groups cooperate in projecting identical items that collide in mid-air at distances from 10 to 80 feet.
Horizontal Injector	A tennis ball or golf ball is projected as straight as possible down a horizontal ramp, and must pass between 2 posts.
Sewer Pipe Missile	Modification of tennis ball catapult: tennis balls must be dropped into a barrel about 50 feet away. The barrel replaces a "sewer pipe" that was the intended target until university maintenance removed it!!

The project was to be about 14 weeks in duration, commencing the second week of classes, and ending with "Evaluation Day," when each design group was to subject their device to final testing and evaluation, and the submission of the final technical report. The scheduling of Evaluation Day would correspond to the normally scheduled final examination period, and the event was conducted on the drill field directly east of the Powell Marine Engineering Complex (PMEC), where most of the engineering offices, classrooms, and laboratories are housed.

Figure 1 shows the progression of activities in the project and the weeks in which these activities were performed. Note that there was a significant delay between the Week 2 classroom period, when the research and development project was introduced, and the Week 6 classroom period when the student groups first met.

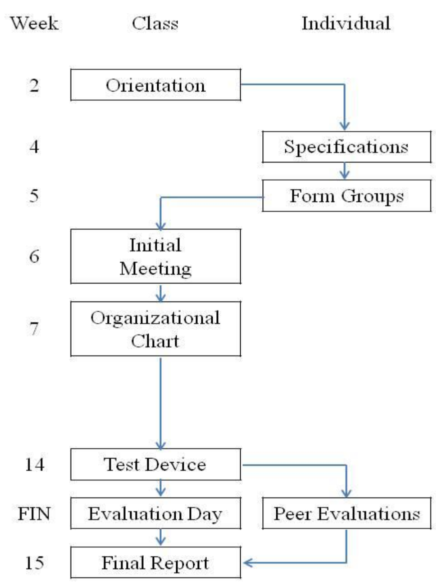

FIGURE 1
PROJECT SCHEDULE DIAGRAM

This basic scheduling pattern was followed during all semesters beginning with the Spring 2010 semester, with a few slight changes from semester to semester, depending on the individual project.

During the Spring 2010 Evaluation Day design groups placed their tennis catapults on or near the edge of the sidewalk adjacent to the drill field. Two distances were randomly selected, and a garbage can lid was placed directly in front of each catapult at that distance from the baseline. Each group was required to adjust their catapult so that it would project a tennis ball and hit the lid. There were three trials at each distance, and a score of 0-25 points was awarded for each trial. A maximum of 25 points was awarded for a direct hit on the lid. In the event of a miss, one point was subtracted for each foot of distance between the impact point of the ball and the lid. Trials where the ball missed the lid by 25 feet or more were awarded a score of 0. Scores for each of the six trials were added to obtain the final score. Students with the "winning catapult," that is, the catapult with the highest final score, were treated to a pizza party; for all groups this performance score was weighted heavily in the determination of the final project grade.

During subsequent semesters, proceedings were similar and depended on the device being tested, and on Evaluation Day requirements. Figures 2 – 4 depict some of the devices constructed:

FIGURE 2
TENNIS BALL CATAPULT SPRING 2010

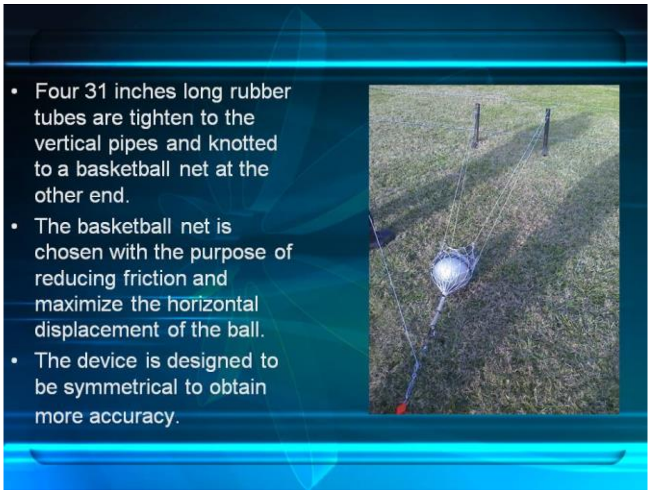

FIGURE 3
MID-AIR COLLIDER FALL 2010

FIGURE 4
SEWER PIPE MISSILE (AIR CANNON) SUMMER 2011

Immediately following the Evaluation Day proceedings, students were given a Peer Evaluation Form by which they were required to evaluate each member of their team. On a simple 1 – 10 scale, with 10 the best, students rated the overall competence (on one scale) and effort level (on a second scale) of their fellow team members. There was also a special box to check if, in the opinion of the student filling out of form, a team member did not contribute at all to the overall functioning of the team. Students were also asked to add special comments concerning any team member who went beyond normal levels of effectiveness and/or effort in accomplishing team objectives.

On the basis of these evaluations, students were assigned and “multiple” ranging between 0.8 and 1.2, applied to their project score, which ranged from 0 to 200. In extreme negative cases, when three or more students checked the “no effort” box for a student, the team was consulted and the student assigned a lower multiple. A few cases occurred each semester where a student essentially “dropped out” of the project, and was hence assigned only a small amount of credit for work completed.

The project was concluded by submission of a Final Technical Report, due at the end of Final Examination Week. Included in the report were specifications developed by the group as a whole, a device description, and accompanying technical drawings. One facet of this report involved a “comments and lessons learned section” which is discussed in more detail in the following section.

RESULTS

Perhaps the most surprising aspect of the entire project was the ability of the students, many of whom had never engaged in a project of this nature, to construct devices that accurately performed their prescribed functions. In the case of the tennis ball catapults, nearly all groups were able to design and build tennis catapults that projected the tennis balls to within a few feet of the target for all six trials. Horizontal injectors were able to project golf balls or tennis balls down a long ramp and through the guideposts as required more than 50% of the time. Most mid-air collider devices were able to collide such identical objects as soccer balls or beach balls at distances of 40 – 50 feet. And … the dramatic deposition of a tennis ball, a “sewer pipe missile” so to speak, into a barrel from a firing device nearly 100 feet away occurred on occasion, resulting in loud cheers from all of the students.

Another interesting result of the project was the huge variation in design types. Lack of originality certainly was not a problem. Devices included spring-loaded seesaw devices, crossbows, spring-loaded pinball shooters, and even an air-powered cannon capable of projecting tennis balls up to 300 feet! Some devices were easier to operate than others! Many students started with wildly imaginative design concepts, and at some point during the construction of the devices imagination collided with the engineering realities of material limitations and difficulties in device control. One group as a result added the rather blunt comment to their final report, “To conclude, these mini-disasters made us aware of the fact that a good idea on paper or in one’s brain is not necessarily a useful design in the real world” [11].

Yet these realities were not enough to limit the proliferation of designs, and it was certainly concluded that there is more than one way to build an engineering device to meet specifications.

During the project students experimented with various organizational structures, and it was found that a "functional structure" was most effective in accomplishing the desired mission. Each student was assigned particular duties, and her or his title generally reflected those duties. Aside from the group leader, who was generally designated "Project Manager" or "Design Team Leader," commonly used job titles were:

(1) Recorder - responsible for editing and submitting reports.

(2) Tester - responsible for testing the device and determining control settings for each possible distance.

(3) Builders - charged with actually building the device.

(4) Personnel Director - in charge of arranging meetings, contacting group members, and insuring that each member was performing assigned duties.

(5) Treasurer - responsible for keeping receipts and obtaining reimbursement for costs at the end of the semester.

Learning the practical aspects of working as a team was one of the more rewarding aspects for many of the students. During the Fall 2011 Semester mid-air collider project, one student from the Palladium design group (design groups were generally named after elements) wrote, “There were many lessons that I learned throughout the course of this project that I know will be helpful in the future. The most important was that teamwork is the only way to succeed with a group project. Although at the beginning we tried to assign separate jobs and have every person work on their own part, in reality what happened was that we ended up working together on everything, sharing ideas and fixing each other’s mistakes” [12].

Students also discovered during device testing, particularly with the tennis catapult and sewer pipe missile projects, the advantages of a device with one controlling variable. With an average of 30 settings for this controlling variable, and a minimum of three trials per setting, about 90 trials needed to be conducted. For devices with more than one controlling variable, however, testing requirements were prohibitive (under the assumptions given above, 2700 trials would be needed for a device with two controlling variables and 81000 trials for a device with three). As a result, most groups initially designing a device with two or more controlling variables modified their devices to operate on a single controlling variable by the time the devices were tested.

In two areas the project did not proceed as well as expected. Because the required projects were not technically advanced, students were able to obtain needed supplies and equipment from local retailers, and had neither the time nor the inclination to utilize the more advanced procurement methods presented in class. Groups that designed and built the air-powered cannons and needed an air compressor, for example, were usually able to borrow one from a relative of one of the group members. The other difficulty stemmed from the artificial nature of the project objective; namely, that the "client company" and “client objective” were simulated rather than real. Hence the students did not experience the dynamics of dealing with a real client. Several researchers have concluded solving a design problem posed by real people in a real context probably constitutes a significantly to the overall educational experience. Daly, Adams, and Bodner, for example, in a recent work discussing the experiences of design professionals state, “… if that same problem is viewed as a design problem, a problem with real context and real people, with objective and subjective ideas about the qualities of good and bad designs, the task is likely to be approached differently” [13].

CONCLUSION

It can be concluded from the above that the project objectives were met, although additional project development and modification is needed to address the two weaknesses mentioned above. Students did receive serious training in research and development aspects normally beyond the scope of a introductory engineering course, and exhibited remarkable capabilities for designing and building devices that performed according to specifications. One student summed up their learning experience as follows: "From this engineering project I learned how to work as a team to coordinate between the building and design processes of a design project. I learned how to work with metal in the machine shop, put proper calculations on paper for practical purposes, and how to schedule meeting times in a group setting. This project really helped me know what is involved in engineering design. I believe that my experiences here will help me in the future when I’m working under the management of an engineering firm and need to complete a project by a deadline. Eventually, the leadership and time management skills I learned will help me run my own engineering firm” [14].

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