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Using the ASME Student Design Competition as the Culminating Design and Build Experience in a Freshman Level CAD-CAM Course

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Abstract

The culminating project in a freshman level CAD/CAM course introduces students to electromechanical and/or pneumo-mechanical systems and drivetrains. In addition, it provides a third opportunity for students to explore the design process and to complete a design and build project. For two consecutive years, student groups participated in a modified version of the ASME Student Design Competition to fulfill this requirement. Adherence to the formal design process was enforced and monitored through intermediate project submissions. The objectives of learning the design process, electromechanical design, and exposure to design and build were achieved. Overall, using the ASME Student Design Competition as a basis for the freshman design experience was a success and will be repeated in future years based on the suitability of the design problem posed.

Introduction

Introducing a design and build project in the first semester of the engineering curriculum, exposes students to open-ended problem solving. This simulates real world engineering practice and develops interest in pursuing engineering education. [1] Graduates of project-based engineering programs, in comparison to traditional programs, are stronger in team skills, communication, ability to carry out total project and generally more adaptable. This leads to them being more employable upon graduation [2] Surveys taken by Hendy and Hadgraft found that the previously mentioned characteristics were the upside to project-based education and also noted that the downside, according to students, was a greater time investment during their time at school [3]

Design and build projects in engineering courses provide students the opportunity to develop skills related to open-ended problem solving such as developing design criteria, benchmarking, concept generation, concept selection, prototyping, testing and design revision. In addition, each exposure to open-ended problems allows them to become more comfortable with the ambiguity inherently involved in design. In a project based learning environment, students are also expected to learn how to integrate multiple design elements into a single unit capable of performing several tasks. This often involves electro-mechanical or pneumo-mechanical systems.

Each year, ASME organizes a student design competition with a unique, open-ended problem statement. In recent years, the problems presented have been appropriate to freshman and sophomore engineering students and making them an excellent choice for integration in a freshman level course with a design and build element.

The competition was used in a required, first semester, freshman level computer aided design and manufacturing course to develop the students open-ended problem solving skills, research skills, integration skills and knowledge of the design process. Students in this course will choose majors from four different engineering disciplines – mechanical, electrical, computer, product design/manufacturing, and therefore, an introduction to as many disciplines as is practical is desired. Students participating in the design project also learn that solutions are rarely achieved utilizing only the knowledge base from a single engineering discipline.

Finally, no program of study can teach an individual everything they will possibly need to know during their professional careers. Therefore, it is crucial for students to develop research skills that will allow them to find solutions to problems for which they have little background knowledge.

Procedure

During the first eight weeks of a fifteen week CAD/CAM course, students were required to complete two design and build projects. These were an impromptu design project and design of a gusset. The scope and learning objectives are shown in Table 1. In all projects, students were required to follow the design process as outlined in Figure 1 and instructed that the design process is iterative and engineers often return to earlier steps as new information becomes available.

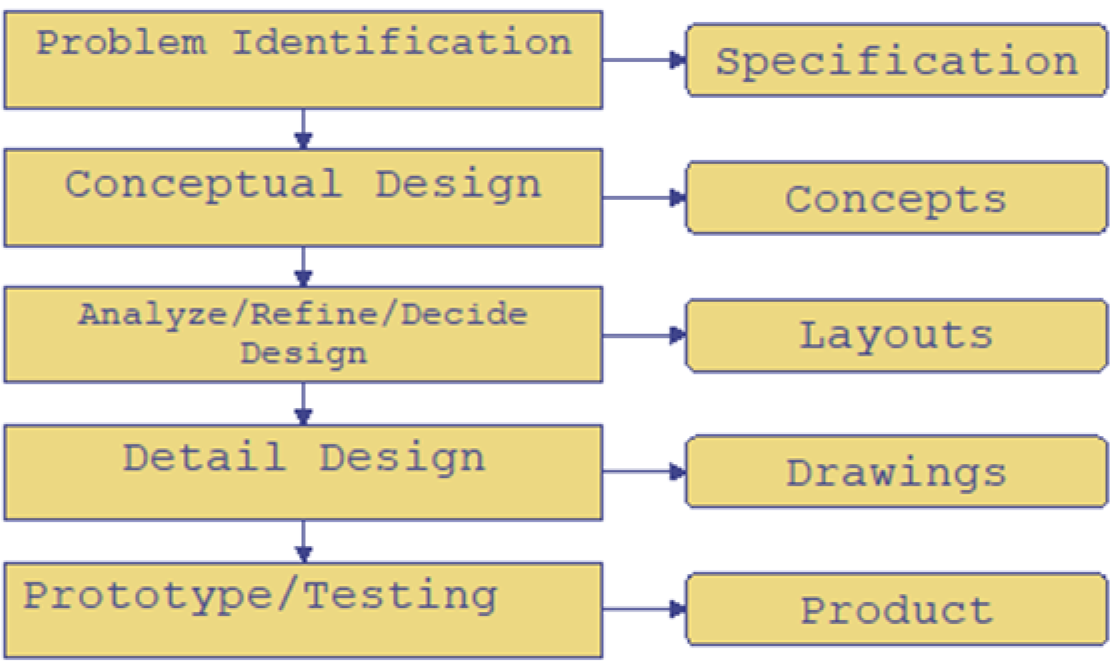

Figure 1—Schematic of Design Process

In the eighth week, student groups, consisting of two to three students, were assigned the task of creating a prototype vehicle which satisfied a modified version of the ASME Student Design Competition. Students were required to research the problem, develop design criteria, benchmark designs, generate a morphological chart and conceptual design solutions, prototype early design ideas, choose a design solution to pursue based on the design requirements using a decision matrix, build a working prototype, test the prototype and iterate prior to the course design competition. In addition to the physical model of their design, students were required to generate a complete CAD model and working drawings. Some materials were supplied for early conceptual prototype construction. However, most supplies for construction of the final prototype were at the students' expense.

Table 1—Design Opportunities

Experience	Lab Periods	Learning Objectives	Scope	Deliverables
Impromptu Design	2	Understand design process	Simple design problem, emphasis on design process	Documentation of all design phases, physical model
Gussett	4-7	Integrate design tools (FEA) to refine design	Single part design, reinforce design process, use design tools	Documentation of all design phases, physical model
Final Project	8-15	Encourage independent learning, Understand need to iterate design	Multiple part design, independent research of components, design refinement	Documentation of all design phases, working device, analysis of performance

In addition to the design requirements stipulated by the competition, students were required to design and machine at least one part of their device. Additionally, the use of tape, paper and cardboard as construction materials was forbidden.

1. Year One

In the first year, the ASME Student Design Competition problem was an Energy Relay [4]. In this competition, teams were required to design four vehicles to complete a relay race. Bonus points were awarded for using different energy sources in the vehicles.

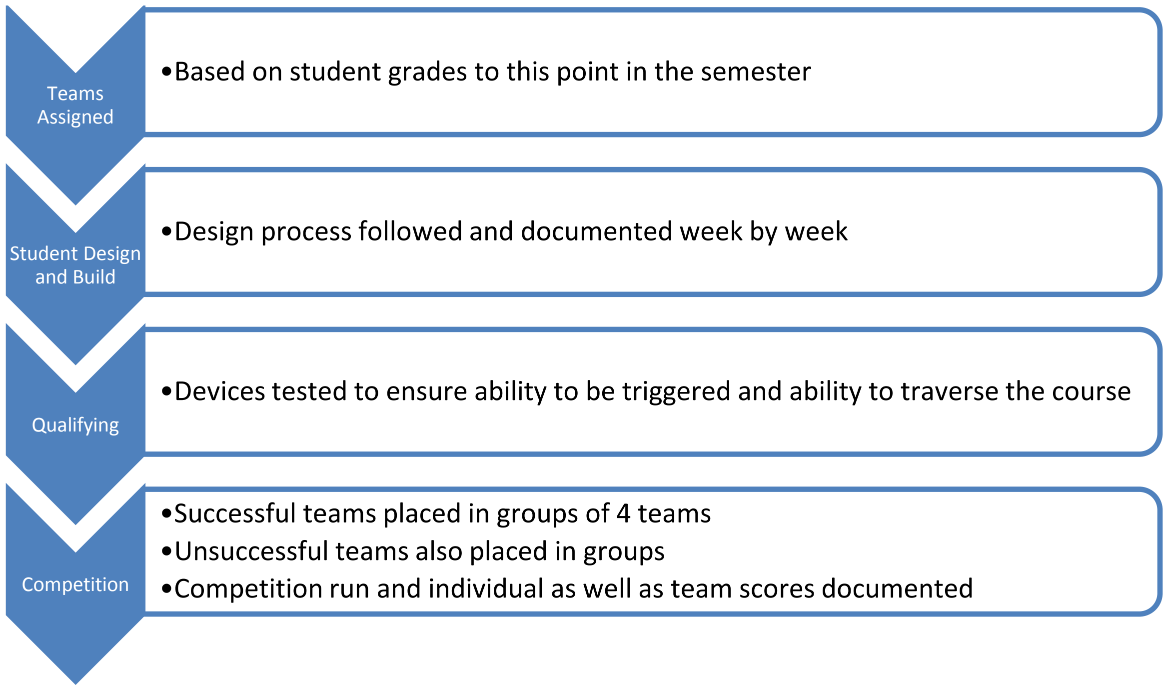

Figure 2—Year One Project Flow Chart

Students were required to produce one vehicle with whatever energy source they chose. Students were informed that the reward for being the best performing vehicle in their energy class was an all-expense paid trip to the ASME District Student Design Competition.

The process for year one is shown in Figure 2. Prior to the course competition, qualifying was conducted to ensure that the groups could perform the intended tasks: trigger and be triggered by another vehicle and traverse a ten meter distance within a one-half meter wide lane. Those who qualified were placed in one competition class and the others were placed in a second competition class. At the final design competition, held after the fifteenth week of class, each student group was paired with three other student groups in their competition class at random to compete in the relay.

In addition to being placed in competition classes, each group was also classified based on the energy source used by their vehicle. Since bonus points were awarded for alternative energy sources in the scoring scheme for the ASME competition, this was used as a criterion to determine which groups would be included in the teams going to the ASME district competition. Groups were scored both as individual prototypes and as relay teams. Two teams from each energy source group were invited to compete in the ASME district competition.

Those groups proceeding to the district competition were divided onto relay teams based on the energy source used in their vehicle. These teams then modified their vehicles for two additional months to work together to complete the relay in the best possible time at the district competition.

2. Year Two

In the second year, the ASME Student Design Competition was Remote Inspection Device [5]. There were two modifications to the procedure from year one for year two. First, the students were not invited to the ASME district competition, although they were informed that it existed and they could compete if they had a working device on competition day. Secondly, students were broken into teams of two or three students. Teams were immediately paired with another team to design a total of two devices to best accomplish the task. Strategy on how to divide tasks was left to the student groups.

Results and Discussion

There were six learning goals in using the ASME Student Design Competition as the culminating design experience in the CAD/CAM course—motivate students through providing a reward for achieving the goals of the project, develop their open-ended problem solving skills, integrate knowledge from the various disciplines of engineering, develop life-long learning skills by exploring material not specifically covered in the course, learn and utilize the full design process to optimize their design concepts, and develop their teamwork and interpersonal skills.

I. Student Motivation
In year one, a total of eighty-nine groups competed in the end of the semester competition with three groups competing in two relays to ensure everyone had the opportunity to compete. These groups were placed in seven energy categories: battery, solar, wind, capacitance, rubber band and spring. A total of sixteen groups were invited to compete at the district competition. Fifty-two groups passed the qualifying round resulting in thirteen relay teams (four vehicles per team) that were competing for the highest honors. The remaining thirty-seven groups were also placed in relay teams and allowed to compete although they were not competing to attend the district competition.

Sixteen groups were invited to attend the district competition. The top two finishers from each energy category were invited in addition to four teams that, although they did not finish in the top spots, were deemed by the faculty to have the most potential to succeed moving forward. One energy category, capacitance, only had one team competing and that team, therefore, was automatically invited to the district competition.

In year two, forty-eight teams competed all of which were able to accomplish at least a portion of the assigned task.

The retention rate from this course from 2008 through 2010 was 67.0 $\pm$ 1.8%. Retention in year one was 76.4%, a significant increase over previous years. However, retention in year two was only 63%. This year, two things changed in this course, the CAD software used was changed from Pro-E to SolidWorks and the ASME Student Design Competition was used for the course project in place of an internally generated course project. When using the internally generated project, the project grade was the only incentive to do well on the project versus the opportunity to compete at a higher level.

There were multiple factors which may have contributed to the increase, and subsequent decrease, in retention. First and foremost, the change from Pro-E to SolidWorks significantly flattened the learning curve for CAD. Secondly, the incentive for success in the project may have motivated some students both to stay in engineering and perform better in the class. Lastly, the effects of the downturn in the economy on student attitudes about education in general and choosing a field of study with significant employment opportunities cannot be overlooked. This last point may also explain the decrease in retention in the second year of this approach. It is possible that more, less qualified, students may be applying to the engineering program in the hopes of securing stable employment after graduation. The final, perhaps obvious, cause may be that the 76% retention rate in a single year may have been an anomaly.

II. Open-ended Problem Solving Skills

Both years, the students gained experience in confronting the ambiguity of design problems. Through the design competition and watching their fellow students, they learned that there are many acceptable solutions to real problems. This is in direct contrast to mathematics and science courses where there is only one correct answer.

Given the diversity of possible solution concepts, students were encouraged to explore a variety of solution options rather than simply determining a single course of action and pursuing that. In addition, most students needed to perform some degree of redesign due to original concepts not producing as expected.

III. Engineering Knowledge Integration

The Energy Relay was uniquely suited to requiring students to research engineering solutions to design problems. Designing a vehicle that used an alternative energy source forced integration of students' knowledge from different engineering disciplines and performing research to determine which energy source would be most effective and seamlessly integrated. However, any electro-mechanical device requires research into drivetrain design and control.

As all solutions required the construction of a vehicle that accomplish an assigned task, some mechanical ability was required regardless of the task to be completed. In addition, product design and manufacturing skills were evident in the adherence to the design process and designing and machining at least one part of their device. In year one, some students made energy choices that allowed them to entirely avoid developing any electrical engineering skills. For example, students who used elastic potential energy as an energy source and were able to construct a mechanical activation method avoided using electricity in their designs entirely. Year two's problem, required integration of a vision system as well as motor controls. Students need to integrate knowledge from multiple engineering disciplines in their solutions.

IV. Life-long Learning Skills

When approaching a new project, benchmarking is a critical tool to learn how others have approached similar problems. It also serves as a launching pad for new ideas. Students were taught effective benchmarking strategies as well as research tools to perform the benchmarking. This introduction enabled them to develop more advanced designs as well as to research the products that were used in implementing their designs.

As the design problem in year one involved choosing an energy source, students researched the various alternative energy sources currently available. In year two, students were required to control their devices without directly seeing the device, this required research into vision systems.

Additionally, they were required to research and purchase all components for their designs. This included not only deciding what types of components they used, but also sourcing those components and deciding on specific brands and vendors. A maximum budget was set as a design requirement. Students were then required to report the amount of money spent and a cost breakdown for their assembly.

Students resisted this self-guided learning and often would have preferred to have the instructors tell them what was available and how to implement it. They were very tentative about developing this new skill. As students in a traditional K-12 educational structure do very little independent learning, this was unfamiliar and uncomfortable for them. However, as the quality of the finished projects proves, this new skill was acquired and refined during the course of the project.

V. Design Process

In addition to seeing diverse possible solutions, students also learned the formal design process as well as how to use morphological matrices and decision matrices to enhance the design process. These tools are used throughout the curriculum in future courses and enhance the students' problem solving abilities.

All design teams were required to submit interim assignments every week to ensure the design process was followed. The first assignment required a complete list of design constraints gathered from the problem statement as well as their personal constraints, at least three examples of benchmarking – this could be anything from benchmarking of a small subsystem of their device to an entire device—a morphological chart and at least three distinct design concepts.

Students struggled with the concept of design constraints as, at this early stage in their education, they had difficulty determining what limits the design may have. In almost every case, they wanted the professor to supply them with a concrete list of constraints they could then go satisfy. As this would have limited the openness of the design problem, this was avoided. Students later learned that they, indeed, did have their own design constraints that were as important as those given in the problem statement. For example, some teams kept a very tight budget while others wished to limit the time spent developing their designs. These, while natural to all people, were also very real engineering constraints that students needed to learn to handle in real life design situation. The pressures of schedule and budget are always foremost when implementing a new design.

The second interim assignment was prototyping and concept selection. Students were required to prototype three concepts which were either entire systems or subsystems of their design concepts. Upon completion of the prototyping, they constructed a decision matrix based on their design constraints and completed the matrix to decide which concept to pursue. Finally, they developed solid models of each part of their chosen design concept.

During the prototyping phase, students experimented with solar panels, fuel cells, wind energy, batteries, switches, wheels, electric circuits, hobby motors and size constraints. The quality of the results and the amount learned by the groups was highly dependent on their motivation.

However, in all cases, students were able to eliminate some of their design concepts based on feasibility.

When developing solid models of their designs, students were forced to work through issues of spacing and attachment as well as the mechanics of how their device would operate. This was very enlightening as those students who had "designed and built" projects before were unaccustomed to needing to work out these details before machining. In the past, they had always worked them out as they built their designs. Those students who had never before attempted to design something had an even harder time with this requirement. One of the biggest obstacles all teams faced was developing the ability to visualize the design without constructing it. This is one of the most valuable skills gained through this type of project.

Detailed drawings were required as well as an assembly and bill of materials for the device as a form of working drawings. At this point in the project, the models of the devices matched the proposed designs, however, the designs had not yet been constructed. All models were required to be updated as modifications were made to the devices as they were built.

Students developed g-codes to machine the manufactured parts of their devices as well as manufacturing process plans for all machined parts. The requirement for this phase of the project was that someone else should be able to manufacture their parts for them from the documentation supplied. This was also a new experience for the students.

Finally, teams assembled and tested their devices prior to the competition. As with any design, students discovered that their devices did not perform exactly as expected and revisions were made to enhance performance. For those groups who devoted themselves to the researching as much as possible in the early stages of the design process, there were only minor modifications to be made. For those who were less diligent in the early phases, substantial changes were needed and some even found they needed to redesign the entire device to meet the requirements before the competition.

VI. Interpersonal Skills

All students were required to work in teams to develop their devices. At the beginning of the project, prior to beginning the design work, they were required to read literature on working in teams—"So, you're going to be a member of a team. . . ." [6] In addition, student feedback was solicited by the professors frequently throughout the project to mediate when needed in team disputes. As could be anticipated, this met with varying degrees of success. The in-class interactions proceeded much as would be expected from a group of freshman students.

Attendance at the District ASME competition required a further level of communication over a longer period than a single course. Some of the interactions when organizing the teams to attend the District Competition were of more interest. Meetings were organized early in the winter semester to establish teams, goals and define the process for attending the district competition. At this time, students were asked to continue meeting to modify their devices and ensure each team would be capable of finishing the relay at the district competition.

Despite numerous attempts by faculty to facilitate team communication, only two teams were ready to attend the district competition. One of the teams communicated well within the team and helped each other modify their devices. This team was led by a non-traditional student and a traditional student with previous leadership experience. It consisted of four groups each with a different energy source and truly fulfilled the intent of the professors organizing the event. The other team was led by a single determined individual. This team consisted of one original project group who, at the last minute, procured devices from former class mates and modified the devices to constitute a relay team. While both of these teams did well at the district competition, the lack of leadership within the student groups showed that developing leadership and communication skills should be an emphasis in freshman programs.

Conclusions

The ASME Student Design Competition provided an excellent framework for teaching students how to solve design problems, develop their research skills, and practice the engineering design process. Solving open-ended problems and all of the obstacles encountered therein are foreign to most young people. As engineers, it is crucial that these skills be developed. Therefore, design challenges should be utilized as early in the curriculum and as frequently as possible.

Caution should be used when determining if any problem, including the design competition is suitable to the learning objectives of the course in which it is introduced. The Energy Relay allowed some students to avoid integrating knowledge from various fields of engineering in their designs. As this was an objective of the course, this was an unforeseen consequence of choosing the design competition as a basis for the culminating design experience in the course.

All of the six stated goals for the project could have been met using any project suitable to the course. However, there were some advantages to using the ASME Student Design Competition as the project. Some additional motivation was achieved by offering the opportunity to attend the District Competition. This came at some cost to the professors leading the activity as much guidance was needed to prepare the students for the competition. Traditionally, a Q&A forum is provided to the students in this course when they are working on design projects. An advantage of using the ASME Competition is that this forum is provided by ASME given that the problem is not modified to fit the course. Students who attended the District Competition had a networking opportunity that would not otherwise have occurred.

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