A Project-Based Freshman Engineering Design Experience - FIRST

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Abstract

During the Spring Semester of 1997, a freshman engineering class was immersed into the engineering design process by working side-by-side with faculty, engineers and high school students to design and construct a robot to compete in the FIRST Competition. The students studied and applied a nine step design process to bring their conceptual paper designs to life by building a 3'x'3'x4', 120 pound robot in just six weeks. Based on student feedback, this hands-on application of the engineering design process was much more effective (and more fun) than the traditional lecture style course. The freshman felt they learned a great deal more about 'real' engineering when faced with deadlines, budget constraints, teamwork conflicts, the laws of physics, etc. The FIRST robot competition is an ideal project to expose freshman to the engineering design process.

Background

The Introduction to Engineering Design (IED) course at the U.S. Coast Guard Academy (USCGA) is a one semester course and is part of the core curriculum taken by all freshmen. The course begins with a nine step design process[1] to provide a logical technique for solving problems encountered throughout the semester. The problems involve various engineering disciplines such as naval architecture, mechanical engineering, civil engineering, engineering economics, etc., as well as several 'liberal arts' topics including creativity, ethics, and TQM[2]. In a radical departure from this traditional IED course, one of the six sections competed in a robotic competition involving industry and high schools called FIRST (For Inspiration and Recognition of Science and Technology).

The FIRST Competition began in 1992 in Manchester, NH. The USCGA has been involved since 1994 as part of the mechanical engineering senior design projects. As stated in the FIRST literature[3], "The Competition is a national engineering contest which immerses high school students in the exciting world of engineering. Teaming up with engineers from businesses and universities, students get a hands-on, inside look at the engineering profession. In six intense weeks, students and engineers work together to brainstorm, design, construct and test their 'champion robot.' With only six weeks, all jobs are critical path. The teams then compete in a spirited, no-holds-barred tournament complete with referees, spectators, cheerleaders and time clocks." The FIRST Competition is an ideal venue to introduce students to engineering design, and immerses them into a hands-on design experience complete with budgets, deadlines and other factors that challenge their project management skills. This paper outlines how USCGA incorporates the FIRST project into the Introduction to Engineering Design course, and how the project provides a real life application of the nine step design process.

FIRST and the Design Process

The FIRST team at USCGA consists of engineers from Northeast Utilities power company, mechanical engineering faculty, 20 freshmen enrolled in the IED course, and students and teachers from two local high schools. The team devotes three hours per day, six afternoons a week, to construct the robot at the lab facilities at USCGA. The initial eight weeks of the 3.0 credit IED course is devoted to the FIRST project. The second half of the semester analyzes the project in light of engineering fundamentals (forces, moments, energy, etc.), and documents the work with oral and written reports.

Eide defines the engineering design process as an orderly, systematic approach to a desired end[1]. This problem solving process is continuous and cyclic in nature in that one proceeds in a step-by-step manner through the nine steps, but often cycles through the process at various steps as the solution evolves. The specific process taught in the IED course involves the following nine steps: *Identify the Need, Define Problem, Search, Criteria and Constraints, Alternative Solutions, Analysis, Decision, Specification, and Communication*. The FIRST project incorporates these steps in a tangible manner that provides the students with an ideal engineering design experience.

The FIRST Competition begins in early January with the unveiling of the playing field and the distribution of a parts kit to each team. The nature of the competition, which varies each year, is revealed at a Kick-Off Workshop in New Hampshire; therefore, everyone starts the project without any prior knowledge of the specific game. Following this workshop, our team spends the first week working in groups to brainstorm conceptual designs that will successfully compete in the game. One useful technique is to draw analogies between the robotic competition and a specific sport. During a 'mechanical football' competition, our team chose a tank-tread drive system to provide better traction--much like an offensive lineman holding his position against a rushing defender. Each group develops sketches, constructs card board models, devises playing strategies, and identifies a preliminary bill of materials to formulate their vision of a competitive robot. While the groups are developing their conceptual designs, several of the engineers construct a scale model of the actual playing field with goal (this is essential to the project) for use in designing and testing the robot. At the end of the first week, each group markets their design to the entire team. Once a consensus is reached, the design proceeds to the prototype stage.

Without even realizing it, the students experience the first seven steps of the design process during this intense first week. The *Need is Identified* by the FIRST committee: to design and build a remote-controlled robot during a six week period to compete in a two minute round against two other teams. The *Problem is Defined* clearly by the competition rules and nature of the game. However, as Eide notes[1], one must avoid the temptation to quickly construct a mental picture of a robot that will satisfy the need in order to consider a wide range of alternatives to <u>best</u> solve the problem at hand. The *Problem Definition* is often revised based on the team's chosen offensive or defensive strategy. In developing their conceptual design, the students *Search* for information from various sources. They use the engineer and faculty experience available, review video clips of past competitions, experiment with design and creativity software, study how other vehicles and mechanisms work, etc.. Next, the competition's *Criteria and Constraints* involving cost, materials, size and weight are considered to develop a feasible *Alternative Solution*. Finally, the entire team uses a decision matrix[1] to compare the *Alternative Solutions* with the *Criteria* to select one conceptual design to work with. Each of the criteria--such as size, weight, 'scorability'--are assigned a weighting factor and then rated on a scale of one to ten by each group. This selection process involves both the *Analysis* and *Decision* steps of the design process.

The 'real' hands-on work begins during the next two weeks of the project, which could be called the 'sub-system prototype stage.' Each robot must be able to maneuver quickly around the playing field, retrieve their team's balls, and finally deliver the balls to the goal. These three functions allow for the concurrent detailed design and prototype construction of the drive system, ball-retrieval mechanism, and scoring mechanism. The team divides into three groups to construct working prototypes using cardboard, wood, PVC pipe, legos, and even computer simulation software to validate their conceptual design. While constructing their prototype, each team must ensure that their device is constructed with 'legal' materials listed in the rules, and can be operated efficiently using the available power sources.

During this sub-system prototype stage, the students revisit several steps of the design process. They must continue their *Search* to develop an efficient mechanism using numerous possible materials. This involves *Analysis* of their designs within the specified *Criteria and Constraints* involving cost, allowable material, size, and weight. The *Analysis* may involve a test to see if the ball is capable of being lifted to the specified height using the motor provided in the parts kit. The drive system group may also test the time it takes to maneuver across the playing field in analyzing their prototype. As the conceptual design prototypes fail to perform as desired, the students pursue alternate concepts and continue their spiral through the design process.

With only six weeks to complete the project, the fourth and fifth weeks involve refinement of sub-systems into finished mechanisms, and then the interface and assembly of the three sub-systems into an operating robot. The interface is critical to minimize interferences between components, as well as ensure the robot is easily repairable. The interface must also ensure a smooth transition from the ball retrieval mechanism to the scoring system. During this stage of the project, the 'young engineers' must provide detailed *Specifications* to the engineers and technicians fabricating the robot. During sub-systems assembly, the team finalizes the control system design by specifying the use of each of the six motors, and how they will be operated with joysticks and switches.

If the project is on schedule, the team devotes the final week to testing. One of the constraints imposed by the FIRST organization is that the robot is operated by two high school students at the competition. Therefore, it is essential that the students are extremely familiar with all aspects of operating the robot. We have used this last week to allow the students to compete against one another to see who is most proficient at driving. Just like any sporting event, the drivers must be able to handle the pressures imposed by the other competitors and the clock during the competition. While the testing is being conducted, other members of the team are busy fabricating spare parts and assembling a tool kit to take to the competition.

Curriculum Benefits

As seen in the previous section, the FIRST project provides an excellent opportunity for students to experience the design process, and not just study it in the classroom. This hands-on experience truly enhances the learning process. West[4] notes, "Even the most elementary hands-on experience teaches a profound lesson: the difference between what you can conceive and what you can build."

The FIRST project is also the foundation for the second half of the Introduction to Engineering Design (IED) course. During this part of the course, the students revisit the classroom to analyze what they just learned and constructed in six weeks of lab! The curriculum addresses basic mechanics and energy principles using the robot they designed as a platform. The students learn to draw proper free-body diagrams depicting their robot scoring a ball on a ramp to determine the coefficient of friction required to hold their wheels in place. They also explore the transfer of energy between electrical, kinetic, and potential during the different stages of the two minute competition.

Next, the students explore the basics of engineering economics in the context of the project. For example, what was the sponsor's cash flow over the life of the project? They then analyze various savings plans to fund the project in future years considering inflation, compound interest, and the time value of money. Other topics addressed in the IED course include creativity, critical thinking, teamwork, and leadership.

Finally, the course winds-up at the ninth step of the design process--*Communication*. Each of the sub-system groups produces a technical report documenting their design experience with the FIRST robot. Along with the written report, they must develop a slide-show (Power Point software) and make an oral presentation to their classmates and faculty to effectively communicate their designs to others.

Conclusion

The 1997 FIRST Competition involved collecting 24 inch diameter tire inner tubes, and placing them on a rotating, eight foot tall toroidal shaped goal. Three robots competed simultaneously to score as many of their nine inner tubes within the two minute period. Each of the three sides of the goal had three pegs protruding from them. Each tube placed on a peg was worth one point, and the total score was doubled if the robot could place three tubes in a vertical row, or one tube on top of the goal's apex.

Using the design process described earlier, the freshman IED class' robot--named DeadRinger--consisted of an elevating arm, complete with elbow, wrist, and hand. This design was able to pick up and place tubes on any peg, as well as on the apex. To maximize scoring, the freshman incorporated a detachable cone into the design of Dead Ringer. This cone was able to hold three tubes which were placed on the apex for a total of 24 points. The three tubes were each worth one point, and then the entire score was doubled three times.

As originally planned, the design was complete in five weeks, allowing time for testing and refinement during the final week. By completing the project on schedule, several high school students were given the opportunity to drive the robot and hone their scoring techniques prior to the actual competition. (The results of the actual competition were unavailable at the time of this writing.)

The entire team was extremely satisfied with the results of their efforts over the six week project. They applied what they learned to a real life problem, and saw the process work to create a machine from a pile of nuts and bolts. The criteria for the robot developed at the start of the project were attained. Dead Ringer was reliable, scored effectively, and was easy to operate. The success of the project in the eyes of the students made it all worthwhile. The FIRST Competition is an excellent project to introduce freshman to the world of engineering.

References

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