COMPETITIONS AS A VEHICLE FOR TEACHING ENGINEERING DESIGN

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Abstract

The Department of Computer Science and Electrical Engineering at WVU has had an engineering Senior Design Project sequence for nearly 25 years. During the 1997-98 sequence, one undergraduate student design team participated in an IEEE regional design competition. The team members chose their project specifically with the intention of entering their design in this regional competition, in contrast to selecting it from a traditionally compiled list of non-competitive design projects.

This paper describes the experiences of members of the design team as well as the faculty directly involved with the project and the design project sequence. We discuss the use of a competition as a vehicle for teaching design as having several inherent advantages over having each team work on a completely distinct project. Advantages include the possibility of comparatively and objectively evaluating the design ability of each team, and the extremely valuable reflective learning which takes place as the teams discuss the relative strengths and weaknesses of the various designs seen at the competition. We also discuss the disadvantages to such an approach, which may be severe enough to preclude its use.

We conclude that overall, the use of competition as an approach to teaching design is an excellent experience for those involved, in that it gives students experience with teamwork and introduces them to practical problem solving situations. It also seems to bring out their best technically. We conclude further that the use of design competitions for course projects should be encouraged, but that it should not be the only available option, based on some of the weaknesses discussed.

Introduction

IEEE Region 2 has had a Student Paper Contest for many years. In 1996, Dr. Famouri, the new IEEE Region 2 Student Activity Chair elected to develop a student design competition similar to design competitions in other IEEE regions. Such contests likely began at MIT with the development of the Micromouse contest in 1979[1]. Design competitions remain popular at MIT[2], and have spread around the world[3,4]. West Virginia University volunteered to host the competition for the first year in conjunction with the paper contest, which was held in Morgantown on April 8 and 9, 1998. It will be held at Penn State Erie in 1999. Student members of IEEE at WVU agreed to design the contest, build the contest playing field, and to design a robot to compete in the contest but not be eligible for a prize. Teams from Cedarville College, Grove City College, Ohio University, Penn State Erie, West Virginia Institute of Technology, and West Virginia University entered the contest in 1998.

Definitions

In this paper our use of design competition refers to a situation where more than one team of students have been assigned design projects in which all teams are to solve the same problem subject to the same set of constraints. Furthermore, we mean competition to imply that the artifacts produced by the teams are objectively evaluated in a way that causes them to be ranked relative to one another. In contrast, the key feature of our use of the term non-competitive is that the artifact produced is "one of a kind" and must be evaluated in the absolute (validated) against design criteria. The design competition described in this paper was competitive between teams from different schools, but represented a non-competitive design in the context of the design class the students were taking. This provided a clear picture of working in both contexts.

The Competition

The competition was designed to run in several "heats." In the first series of qualifying heats, competing robots performed alone on the playing field, amassing game points related to the number of ball bearings they were able to collect from known locations and deposit in their home bin within a fixed time period. Robots that qualified by accumulating game points in the qualifying rounds were then paired on the playing field for the final rounds of the competition. In this phase the goal remained the same in terms of accumulating game points, but the robots were in direct competition and thus able to interfere with each other. This forced the designers to consider two different collection strategies, one for maximum productivity when no other robot was present on the field, and another more dynamic strategy when another active robot was present.

The Design Team

The students who chose to enter the robot competition came from the natural leaders in the department, and tended to be students who had for several years been engaged in IEEE or other extracurricular activities. They tended to be very strong academically, and to have good management and teamwork skills as a result of their involvement in a variety of activities. They were not a group of average students. The team was made up of five students: Heather Collier, Robert Harman, Brian Inman, Thaddeus Marrara, and Matthew Weatherly.

The Faculty

The IEEE Region 2 robot competition was championed by Dr. Parviz Famouri, who was at the time serving as Chair of the Pittsburgh Section of IEEE. Besides working with the WVU IEEE Student Branch to host the competition, he served as the "client" for the design team mentioned above. He controlled the budget and expressed preferences when the team would have decisions to make about design and performance tradeoffs. He also served as a technical "advisor" for the team, as did several other members of the faculty. The Senior Design Project sequence was coordinated by Dr. Wils Cooley, who also served in the capacity of "monitor" for the project team. The duty of the monitor was to meet with the team weekly to assess progress, to discuss and to suggest solution strategies for technical, management, and interpersonal problems that the team might be having, and to differentiate and assess the contributions of each individual team member. In the 1997-98 academic year there were two other faculty assigned to the Design Project class, Dr. Biswajit Das and Dr. Robert McConnell. The class had a total of 50 students divided into 13 design teams. Each design project faculty member monitored 4 or 5 teams, but all three followed the general progress of each team and participated in the overall assessment of all of the teams at the end of the semester.

The Student Design Team Perspective

As two of the members of the design team, we had several project design experiences in previous classes. These design projects were given to everyone in the class, but there was no competition at the end. In these projects, the teams needed only to provide a design that met all requirements within the given restraints of the design. Designing for a head-to-head public competition was a very different experience, however. In such a design competition, these same elements were involved, but because all projects competing must meet the same criteria, there was an additional drive to surpass the given requirements in order to produce the "best" design. This forced us to look at many options before deciding on any aspect of the design to determine what the best approach was as compared to going with the first approach that worked.

A major feature of designing a project for competition was the drive that it provided to us involved in the design. The competition aspect not only set a desire to do well, but also it added a measure of anxiety associated with failure in a public arena. This anxiety proved to be more of a catalyst toward the assurance of a working project than the course grade. With the drive to win and the fear of public failure, all systems were analyzed during design and after construction. Each portion had to not just work; it had to perform its function more efficiently than systems put up by competitors. The fact that the project would be shown to the public led to completion dates being set which were well in advance of those required by the class. This allowed all last minute work to be used for fine tuning our design rather than just getting it built. We knew very how well our vehicle worked long before the day of the competition.

A further feature of our particular design experience is that we designed the competition as well as designing a robot to enter the competition. This experience forced us to take the first steps of recognizing constraints and requirements and translating them into the rules of the competition as we tried to think in advance about how entering teams would respond to the rules, misinterpret them, or find loop-holes.

The Faculty Perspective

As faculty with a history of involvement in Senior Project Design (Dr. Famouri had previously served as a design project faculty member and project monitor for 3 years, Dr. Cooley has been involved for more than 15 years), we find that working with a team who has entered a student design competition differs in many ways from working with teams not involved in competition.

Several of these are listed and discussed below.

1. Because there is a competition involved, there are "rules." These rules can be translated fairly easily into performance requirements for the design. On the other hand, teams who tackle other types of design challenges often struggle to understand the range of performance characteristics necessary from their deign in order for it to be considered "successful." This makes the first stages in a competition-oriented design much more straightforward than dealing with a "real-world" design. We have seen many teams who have failed because they were never able to develop appropriate design requirements. Teams entering design competitions are unlikely to have such problems. The end result is that designs for competitions are usually superior to student designs for non-competitive projects.

2. Competition-oriented design requirements tend to be limited to technical requirements and economic considerations. On the other hand, ABET asks that student design experiences include many other "realistic" constraints, such as safety, reliability, aesthetics, ethics, and social impact. Although reliability and economics are often issues in competition designs, in terms of the overall educational experience of the design project, competition-oriented designs are probably less rich than tackling a problem in the "real world," especially a project for a client who is outside of academia. This represents a weakness of design competitions.

3. Although design competitions produce contrived problems rather than real ones, the richness of realistic constraints that is missing is often offset by a richness in technical challenge. Well-designed competitions typically require the design team to solve a broad range of technical problems related to sensing, signal processing, drive systems, control systems, algorithms, memory allocation, and optimizations that involve complex trade-offs[2]. Often the real-world design projects our students do are less rich technically because they involve only a small piece of an operating system.

4. Design competitions involving head-to-head competition involve the development of problem-solving strategies. In addition, since many of the competitions are run in heats, teams have the ability to alter their strategy based on their observations of the performance of their competitors. The experience they get in making real-time management decisions as a team can be an extremely valuable lesson to many.

5. Design competitions tend to provide more "closure" for the students than non-competitive design projects. Much of this closure occurs as a result of the competition event itself. The competition forces a real deadline that no amount of cajoling by the design team can change, whereas non-competitive design teams can make a strong argument that the client COULD wait one more day for the final product to be delivered. The competing team also gets to observe the performance of their design at the competition, whereas often the non-competing team often delivers their "baby" off to a distant client, never to be seen again. The full-sensory feedback that the competition provides is a powerful learning tool that may be difficult to provide to teams who are not involved in a competition. On the other hand, the products designed for competitions generally have no practical use outside of the competition, which does not give students the feeling that they have contributed to the good of society in some way.

6. Besides receiving full sensory feedback about the quality of their own artifact, competing design teams often get to see the tangible results of "paths not taken." Design is an iterative process of creating alternatives, modeling and analyzing the alternatives, and then choosing the "best" alternative. When a team sees the construction and performance of the artifacts produced by other teams, they may see the result of pursuing a path which they had considered and rejected. This causes them to reflect about whether or not they did make the best choices, and whether or not their modeling and analysis were appropriate.

Conclusions

Our main conclusion is that design competitions offer a superb way of creating enthusiasm, and reinforcing and even evaluating learning at all levels of engineering education. The principal weaknesses are that they usually do not provide students with much with the earliest stages of design (problem formulation, client needs analysis, development of design requirements), do not force students to deal with "realistic" constraints such as ethics and social impact, and are difficult to tailor to challenge the best students without overwhelming the weakest ones.

Recommendations

We offer several recommendations based on our experience with competition designs and non-competition design.

1. Design competition design projects are easier for students to comprehend as problems, because the key issues of constraints and performance requirements have been dealt with by the designers of the competition and handed to the students as the rules. When students cannot take these first steps or do them poorly, poor designs are the usual result. We suggest that design competitions are more appropriate than non-competitive design projects for lower division students, because the constraints and challenge can be more easily tailored to the maturity of the students. On the other hand, very challenging competitions can be designed to challenge even the most adept advanced-level students.

One solution to providing students engaged in designs for competition with experience in understanding problems and setting design goals would be to ask the class to design the competition itself. This could be done as a precursor to the competition, or it could be reserved until the end, when the class would design a competition for the subsequent offering of the same class. The experience of designing the robot design competition proved to be a valuable part of the overall experience for the students, and we recommend that such an activity be a part of students' overall design experience.

2. Design competitions must be carefully designed. Thus, it is more difficult for the faculty to produce an excellent design experience appropriate to the level of the students than it is to do so by giving them non-competitive projects to choose from. In our experience the constraints on non-competitive design projects are so rich and so general that the design team and the faculty can choose how to deal with the constraints as the project evolves, thus tailoring each project and its

associated level of challenge individually for the team that is involved. Competitions are highly constrained, and therefore have much less "wiggle room" if the task proves to be too difficult for some teams of student designers. This represents a weakness of design competitions, especially if student teams involved differ widely in their technical ability.

3. Non-competition design project classes are much more difficult to manage and grade. Because each team is working on a different project, evaluation of team performances is a difficult process of comparing apples to oranges. As mentioned above, the constraints and requirements tend to evolve along with the design through a negotiation process involving the supervising faculty. Often the faculty cannot agree on relative difficulty among diverse projects. With every team designing subject to the same requirements and constraints, the competition provides an "objective" way of determining who has produced the best design. We recommend that faculty who do not have extensive experience supervising and evaluating student designs implement competition-style design projects.

4. Finally, we suggest that design projects incorporating the realistic constraints demanded by ABET be approached cautiously. Students must be fairly mature to deal with such problems. Ones who are not ready will either be overwhelmed by the complexity of their task or fail to see the richness of the problem as they attack only the technical problems that confront them. In either case, educational goals will not be met.

We also offer two general recommendations, regardless of the type of design class offered.

1. Make sure that the design teams that are formed are all equally committed to the project. Some students are content just to pass, while others will work very hard to achieve their personal best. This does NOT mean that students who have high GPAs will be highly committed while less spectacular students will not be. Level of commitment should be agreed to by team members and reaffirmed periodically throughout the project.

2. Students sometimes need help to understand and appreciate the talents of their team members. Time spent trying to match project subtasks to the talents of the members can pay great dividends. Design faculty often need to help teams with organization and task assignment.

References

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WILS COOLEY

Wils L. Cooley received BSEE, MSEE and PhD degrees from Carnegie-Mellon University. He has been with the faculty at West Virginia University since 1973, and has coordinated and taught in the senior design project course for more than 15 years. He is presently Professor and Associate Chair of Computer Science and Electrical Engineering at West Virginia University. Dr. Cooley is a registered professional engineer in West Virginia.

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Parviz Famouri received his BS degree in Applied Mathematics from Kentucky State University in 1981. He then began his studies at the University of Kentucky, where he received his BS, MS, and Ph.D. degrees in Electrical Engineering in 1982, 1986, and 1990, respectively. He is the author of over 40 papers and presentations. He has also worked for Emerson Motor Company. Dr. Famouri's primary interests include design, analysis, modeling and control of electromechanical systems, electric and hybrid electric vehicles, and power electronics. He has served as Principle Investigator on projects for NSF, DoD and NASA and has been involved with projects funded by Electric Power Research Institute and electric utilities. Dr. Famouri is active in IEEE and he is currently Student Activity Committee Chair for Region 2.

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Brian Inman graduated from West Virginia University in December 1998 with a BS in Computer Engineering. He is part of team that created and administered the first Region II IEEE Hardware Design Competition. He participated in an exchange program at the University of Hertfordshire in England during the 1996 ? 1997 academic year. He was also enlisted as a Nuclear Operator in the U.S. Navy for six years.