Engineering Design Competitions: A Motivating & Learning Experience

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Abstract — *Recognizing the need to increase the talent pool of students pursuing careers in engineering and technology, there have been a host of programs initiated to meet this goal. Such programs have been initiated as part of the school curriculum and as extracurricular activities. Competitions at the local, State and national levels are receiving greater attention as a viable approach to enhancing teaching and learning through hands-on applications.*
Engineering design competitions, that show engineering as a fun experience and applicable to their everyday experiences both in and outside the classroom, can be a learning and motivating experience for students and for coaches. This paper will review the nature of these competitions, and how they might impact on participants. Methods and possible resources for preparing participants and their coaches for the competition will also be reviewed. Strategies for using these experiences to motivate students and to integrate these experiences into secondary school science, math and technology courses will be hypothecated.

Index Terms — *K-12 outreach, Engineering design competitions, Pre-College engineering.*

INTRODUCTION

Continuing progress in SMET fields is essential to meeting the nation's goals of improved international competitiveness and social well being for all citizens. To maintain such capability, our population must be educated in at least the basic concepts of science, mathematics and engineering, and our science pipeline must reflect the diversity of our human resources. A basic understanding of science and mathematics is necessary to meet the need for a technically competent workforce. Students educated in science, math, engineering and technology represent a potential resource for addressing US needs for such personnel.

Engineering plays a major role in shaping the world today. Yet many bright, capable students choose not to pursue sciences in high school, and therefore have no opportunity to enter high paying science, engineering and technology careers [1]. A major reason for their lack of interest in science and engineering is that they see no clear relationship between these subjects and their daily lives [2]. Nor can their science teachers currently give this perspective to them [2]-[3]. While an important reason for many students' failure to pursue engineering careers is lack of academic preparation in high school, especially in science and math, even those students who are adequately prepared and initially choose engineering often do not persist [4].

In the past 20 years there has been a proliferation of programs, mostly by universities, designed to promote interest of young women in STEM careers. Some programs have been making their way into the secondary school classrooms, both as part of the regular school curriculum, and as extracurricular activities. Most of these programs are excellent programs. Unfortunately, it is appears that trying to interest students in STEM careers is not easy.

Competitions at the local, State and national levels are receiving greater attention as a viable approach to enhancing teaching and learning through hands-on applications [5]–[14]. They include regional/national competitions such as US FIRST LEGO League [5]-[6] and BEST [7]-[8], JETS [9], and Botball Robotics [10], as well as local ones [11]-[12]. Some science competitions also include engineering design events [13]-[14]. NJIT participates (as host, judges and event supervisors) and/or supports teams of students in many competitions, including US FIRST Robotics and LEGO League, JETS, the Panasonic Design Challenge [12], NJ Science Olympiad [13], and the NJ Chemistry Olympics [14].

The purpose of this study was to:

- Review the nature of engineering design competitions;
- Explore how competitions might impact on participants.

This study examined the data from two if the competitions, the Panasonic Design Challenge and the High School Robotics Competition. As outcomes, we were looking for:

- Methods and possible resources for better preparing participants and their coaches for the competitions.
- Strategies for using these experiences to motivate students.
- Strategies for integrating these experiences into secondary school science, math and technology courses.

NATURE OF THE COMPETITIONS

For the past fifteen years we have collaborated on the Panasonic Design Challenge since its inception, hosted the JETS TEAMS competition, and supervised/judged an engineering design event (Mission Possible) at the New Jersey Science Olympiad. Last year, we partnered with the Newark (NJ) School District to support school teams in the US FIRST Robotics and LEGO League competitions. Competitions provide teams of students a venue to connect scientific concepts with real-world applications, and allow the students to combine their problem solving skills with acquired knowledge to solve engineering problems. Engineering design competitions can show engineering as a fun experience and applicable to their everyday experiences both in and outside the classroom. For most competitions, the goals usually include any or all of the following:

- To enhance and enrich the knowledge and appreciation of math and science for secondary school students through the application of engineering principles and designs.
- To encourage career exploration in engineering fields.
- To enhance the interest of these students in these fields, and thereby increase the number of potential engineering students entering the profession.

We have observed the competitions in several ways, including the role of judges and the role of observer. This past year, we provided support for the local urban district students as they prepared for the US FIRST Robotics and LEGO League competitions, as well as judges and observers at the State competitions. Our observations and perceptions are as follows:

- The students found the competitions challenging and fun.
- The competitions appeared to provide a positive learning experience for a wide spectrum of students.
- The students were more interested in building devices that worked and less interested in the science and engineering necessary to optimize the operation of the device.

It was the last item that concerned us the most. While everyone seems to agree that these competitions should be a positive learning experience as well as a fun experience for the students, there appears to be little in the literature regarding how to ensure that it is a learning experience in terms of the science and the engineering (and engineering design) that should go into the building of the device. There also appears to be a lack of methods of how to evaluate these learning experiences. The primary focus of the available reports appears to be on the perceptions of students and others involved in the events [6], [9], [15]. There appears to be only one report that tries to quantify the students' understanding of the design process [11].

ASSESSING THE STUDENTS' LEARNING EXPERIENCE

Our initial activity was the development and utilization of a post-competition survey for the engineering design competitions of immediate interest. Appropriate questions were adopted from a project for a freshmen engineering course on robotics [16]. The survey was designed to give us some baseline information and to give us an indication of what students might understand about engineering design. There were two versions of the survey, one for the US FIRST competitions, which included questions on both engineering design and computer programming, and one, which included questions only related to engineering design competitions. This paper will focus on the questions related to engineering design.

The survey was administered after the competitions, on a voluntary basis, to students competing in the FIRST High School Robotics, the FIRST LEGO League, the Panasonic Challenge, the Mission Possible Event of the NJ Science Olympiad and the JETS TEAMS Competition. Initially, we examined student responses to:

1. Describe (briefly) what you think the design process is?
2. How confident are you of your ability to design an object?
3. As a result of this competition, do you feel more confident of your ability to design an object?
4. Has your participation altered your concept of what engineering is or engineers do? If so, how?

A protocol, or checklist, was needed to score the student responses to question 1. Such a protocol has been used in undergraduate freshmen engineering courses to assess student design processes [17]. Since engineering problems are usually different, solutions will also be different. Therefore there is usually not a definitive design process that would satisfy every problem. A checklist was needed that was representative of the process, but included the steps and language that would be understood and used by the students and their coaches. We wanted students to be able to show an organized series of actions that an engineer would take when solving a problem or developing a product. We wanted to be sure that they understood that it was a problem solving process that was iterative in nature and sought the optimum solution to the problem. The protocol we devised was an adaptation of several found in the literature [18]-[21].

The protocol was tested by applying it to the surveys from the participants in the Panasonic Design Challenge (PDC), from which 25 of 44 competition participants completed the survey. The PDC was selected based on our prior experiences with the competition and our knowledge of most of the schools the participants represent. For example, the PDC has cost as a constraint [12]. Thus it is highly likely that design for cost would be a major concern for each student team. Hence, students would likely be looking for the optimum design. We expected that there would be a mix of students who could explain the design process and those who could not. The scores for the PDC are shown in Table 1.

TABLE I

SCORES OF STUDENTS FOR THE PANASONIC DESIGN CHALLENGE AND THE H.S. ROBOTICS COMPETITION

Points	Panasonic Design Challenge (33 Responses)	H.S. Robotics Competition (36 Responses)
0	7	27
1	3	4
2	2	4
3	3	1
4	7	0
5	7	0
6	1	0
7	3	0
8-10	0	0

The results of that survey led to slight refinements of the protocol resulting in the following 10-step process:

1. Identify the Problem
2. Research the Problem (i.e., Gathering & Analyzing Information)
3. Performance Criteria (i.e., Specifications & Constraints)
4. Brainstorm – Alternative Design/Solutions
5. Preliminary Design – Prototype
6. Test – Evaluate
7. Refine
8. Retest
9. Final Design
10. Communication

In view of our university's substantial commitment to the support of the students in the Newark School District participating in the US FIRST High School Robotics Competition, our initial study focused on the responses of those students. During the spring 2004 preparation and actual participation in the competition, it was generally observed that students appeared to lack design knowledge, design process skills and positive attitudes toward design. Students' interest seemed to focus on the "assembly" of the robot rather than seeking the optimum solution to the problem. This observation was also reflected in the students' responses, after the competition, to question #1 (above) about the design process. In scoring the students' responses to this question, each item was assigned one point. Thus the total score for the question would range from 0 to 10. We received responses from 36 students representing 5 different high school teams. Seventy-five percent of the respondents received a score of "0" for the description of the design process. Eleven percent received a score of "1" and another 11% received a score of "2". One student received a score of "3". All scores of "2" and "3" were by students in the same high school.

It was also of interest to look at questions #2 and #3 (above) to see how the perceptions of students matched up with their ability to describe the design process. Seventy-one percent of the students indicated that they were moderately confident of their ability to design an object while 17% were very confident. Further, 86% of the respondents indicated that they felt more confident of their ability to design an object as a result of participating in the competition. Unfortunately, that is not reflected in their description of the design process. Of the students who indicated that they were very confident of their design skills, only one received a score above "0", and that was a score of "1".

We believed that students, as well as teachers, generally needed some formal instruction on both the engineering design process and the subject of robotics, a conclusion also reported elsewhere [5]. We also concluded that there was a need for additional methodologies that provide evidence of gains in student knowledge and skills.

Accordingly, we developed and implemented a pilot 3-week summer robotics enrichment clinic in order to train student leaders for each participating high school in the various components of the FIRST high school robotics competition, including engineering design, robotics, communication skills, and marketing. This pilot program will also result in the development of instructional materials for students and for coaches to use in preparation for the competition.

Pre- and post-surveys were conducted. Ten student participants completed both pre- and post-surveys. On the pre-survey, only 2 of the 10 students received a score greater than "0" and these were scores of 1.5 and 2.0. On the post-survey four students received a score greater than "0". Two of them received a score of "7" (They were also two of the students who received scores greater than "0" on the pre-survey. One student received a score of "6" and one received a score of "4". These results were both disappointing and still somewhat encouraging. However, the use of the protocol was supplemented by anecdotal evidence obtained through observation of the students as they were working on their projects. This evidence appear to show that while students were improving their knowledge and process skills, some of them were unable to convert that understanding into a written statement.

Observing the Summer Robotic Clinic students during preparations for the final challenge helped to highlight their ability to apply newly acquired design skills and computer-programming expertise. However, students, at times were not able to verbalize adaptive strategies that they used in altering the design of their robot. Students tended to internalize this information and used it without formally thinking about it.

Examples of these types of behaviors reflective of newly developed engineering design skills include:

1. Students made last minute computer program changes, altering the number of degrees in the turning formula, thereby allow their robot to have greater ease in making the turns on the lower friction rug that was present on the competition floor covering.
2. When the competition surface was changed from a tiled floor to one with a rug covering, students adapted by changing the robots wheel diameter from larger to smaller in an effort to alter the quality of the friction contact
3. One team experimented with the diameter of the robot's wheels and eventually replaces a single front wheel with a non-moving slide plate to increase vehicle contact with the low friction rug surface.
4. When the wheel of one team's robot had difficulty with the wheel hub spinning inside the tire, due to the higher friction on the wheels, one team grabbed a hot glue gun from the poster construction materials and glued the wheel to the interior hub to stop the slippage of the wheel.

Perhaps the greatest overall example of developing a sense of increased engineering design was reflected in the students' development of an increased ability to move from the "assembly mode" to the "design mode" in the adoptions that they developed to make their robot a stronger competitor in the contest.

As a final note, one of the summer robotics students had also participated in the spring 2004 competition and had responded to the survey conducted for that event. For the spring competition, she scored a "1" with the response:

"The design process is w(h)ere you sit and discuss the plan in which you are going to build your robot."

In this response she appears to refer to a group discussion or brainstorming as part of the design process.

On the summer pre-survey, she scored a "1.5" with the response:

"First you have to know your tasks. Then you have to design your robot to complete that task. After you have design your robot you need to start programming your robot so that it could complete the task."

Here she implies the need for a problem statement and existence of performance criteria.

On the summer post-survey, she scored a "7" with the response:

"The engineering design process includes the steps to take when planning to solve a problem.

- State the problem.
- Brainstorm (make hypotheses about the problem).
- Then do the problem (list the results afterward).
- Make conclusion on the problem.

When doing the engineering design process, the result may not always work. It's your job to keep doing what you are doing until you get a right result."

CONCLUSION

Engineering design competitions were seen to be both a fun experience and a valuable learning experience. However, the learning experience appeared to be limited by the level of the prior experiences and prior knowledge of the students. The results of this effort indicate the need for formal instruction for students to help prepare them for the competitions. Such instruction is critical if students are to have the design knowledge, the design process skills and positive attitudes toward design. Accordingly, after school experiences will be provided to help prepare student teams for the FIRST high school robotics competition. In addition, we have developed several learning outcomes that we expect students to achieve as demonstration that competitions can provide positive learning experiences for students as well as being a "fun" experience.

ACKNOWLEDGEMENT

Funding for this study was provided by a grant from the New Jersey Commission for Higher Education through its Workforce Development Program.

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