THE DESIGN TASC ENGINEERING DESIGN COMPETITION: A TEN-YEAR PERSPECTIVE

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Abstract *– The Design TASC (Technology and Science Connection) Engineering Design Competition, which we created for Vermont high schools, is now in its tenth year. The basic format is still very much the same as described in a previous paper [1]. However, since that time we have learned a great deal about the practical aspects of running this type of competition, as well as how to create design criteria that provide a challenge and a positive learning experience for a wide spectrum of high school juniors and seniors. The primary features of this competition, which include design, construction, documentation, and competition, are reviewed here. In addition, changes that we have incorporated over the years, and feedback from participating students and teachers, are presented. A discussion of the attitudes of students about the relationships among strategy, teamwork, and design is also included.*

INTRODUCTION

We created the Design TASC (Technology and Science Connection) Competition in 1991, with the expressed intent of giving high school seniors an engineering design experience that they might not otherwise have an opportunity to obtain. Since Vermont is a small state geographically and in population, and is very rural in character, we decided that all of the high schools and technical centers in the state should be included (a total of 70 schools). Also, we decided that the competition should present a nearly level playing field for both large urban schools and small rural schools. All problems are designed such that devices that meet the design criteria may be built from inexpensive, readily available materials using simple hand and power tools. The problems are such that a school that might only field a single team with a minimum of two students can still participate in a meaningful way. No outside professional expertise, and no engineering experience on the part of the teacher, is necessary to achieve a successful design solution. External funding or sponsorship of individual teams or schools is unnecessary.

The competition formally begins when the official rules are sent to all schools at the beginning of the Fall term. (A preliminary version of the rules, which includes only a general description of the design topic, is sent to teachers at the end of the Spring term to allow for summer planning). The Competition culminates with the on-campus Performance Competition the first weekend in December. All participating teams bring their devices to the university and compete for the highest score based on the performance rules.

Although an unlimited number of teams and schools may participate in the early stages of the competition, local logistics prevent us from accommodating more than about sixty teams at the one-day on-campus performance event. To keep the size of the competition manageable, each school is allowed to have a maximum of three teams of two to five students each. Thus, some of the larger schools have preliminary contests to select their top three teams.

In addition to the design and build aspects of the competition, there is an equally emphasized documentation aspect. All teams wishing to participate in the competition must provide two pieces of documentation of their design. The first is a design preview that consists of a short discussion and sketches of the team's proposed solution. This is due several weeks after the official rules are distributed. The second, and most important, required document is the Final Design Portfolio. This complete and formal description of the team's apparatus must include a description of the operation of the device, engineering drawings, cost estimates, testing results, and scoring analysis. It is due three days before the on-campus Performance Competition, and is reviewed by a team of engineering faculty and local engineers. The award structure for the Portfolio Competition is equal to that of the Performance Competition.

THE COMPETITION

Goals

The primary goal of the Design TASC Competition is to provide an engineering design experience to high school students, primarily those taking a first course in physics. Students use (and enhance) their knowledge of science and available technology to design and build a device that provides a solution to a specified problem. Students also use (and enhance) their knowledge of grammar and composition by carefully documenting their designs.

Other important educational aspects of the competition include learning teamwork, analysis, optimization, strategy,

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and cost effectiveness. Thus, the competition allows extra-curricular topics to be incorporated into curricular objectives in a meaningful way.

These goals fulfill several of the outcomes listed in the State of Vermont's Framework of Standards and Learning Opportunities for grades PreK-12 [2]. Specifically, the section on Science, Mathematics, and Technology Standards, sub-section Designing Solutions, states: "Students use technological/engineering processes to design solutions to problems. This is evident when students [in grades 9 – 12]:

- Create a design solution;
- Build on specifications, with an understanding of the constraints (e.g. cost, weight, environment), and tolerances that affect performance;
- Include mathematical and/or mechanical models of their design;
- Include steps and sequences for efficiently building a prototype or product that conforms to the specifications;
- Test the prototype;
- Use the results to modify the design;
- Evaluate and adjust a design process, responding to the unique characteristics of a specific problem."

The Design Portfolio aspect of the competition relates directly to the Communication Standards, sub-section Notation and Representation, which states: "Students interpret and communicate using mathematical, scientific, and technological notation and representation. This is evident when students [in grades 9 – 12]:

- Represent data and results in multiple ways (e.g., numbers and statistics, drawings, diagrams and pictures, equations, sentences, charts and tables, models), communicating points effectively;
- Use appropriate scientific, technological, and mathematical vocabulary and formal symbolic notations to communicate simple and complex situations, with clear links between text and representations, symbolic notations and models, diagrams, graphs, etc.;
- Use physical models quantitatively to confirm and communicate relationships and concepts;
- Explain a scientific, mathematical, or technological concept; explain a procedure they have followed to others in enough detail that others could repeat or reproduce the results."

Many other individual standards are touched upon in other aspects of our competition.

Schedule

The timetable of our competition is shown below. The competition is intended to be incorporated into the Fall term curriculum of most junior and senior physics courses.

January:	Creation of a new problem begins.
Late May:	Preliminary information sent to schools.
Late August:	Complete rules and specifications sent out.
Late September:	Schools submit team information.
Mid October:	Teams submit design previews for review.
Late October:	Design previews returned with comments.
Late November:	Larger schools select top three teams.
Early December:	Teams submit Final Design Portfolios.
3 days later:	Performance Competition on-campus.

Format

The format of the Performance Competition is shown below. Each team is allotted a time slot during which they must set up and run their device twice. Teams attempt to maximize their score according to the specified Scoring Formula. The timetable for each time slot is as follows:

Initial setup	10 minutes
First run	5 minutes
Reset time	4 minutes
Second run	5 minutes
Takedown	3 minutes

Each team is scored by a team of three judges consisting of one engineer from local industry and two engineering students. Each judging team handles two performance areas, and one competing team sets up its device while the other is performing its second run. We continuously run ten performance areas with five judging teams, allowing us to handle as many as sixty teams in the morning round. The eight top scoring teams in the first round move to the final round, in which only one run is allowed. The teams run their devices one at a time, starting with the eighth place team from the morning, and only the score in the final round is used to determine the winners.

The format of the Portfolio Competition is as follows. The portfolio judging team (described earlier) selects the top eight portfolios the day before the Performance Competition. The teams whose portfolios are selected are notified as they arrive for the Performance Competition, and are scheduled for a five-minute oral presentation. During the oral presentation they describe their design and allow the judges to examine their device. The judges may also observe the device in competition if they desire. They then select the winners.

Competition Summary

The goals, schedule, and format of the competition, as described above, remain essentially unchanged from the first year. We have moved the Performance Competition back three weeks from mid-November to early December to allow teams more time to build and test their designs, and to avoid conflicts with other events. We have extended each run from 3 minutes to 5 minutes. In general, though, we have found the above format to work very well for us, and for the participating students and teachers. The following sections will describe some of the design problems we have created and used over the past nine years, and explain how and why the problems have evolved. We will also discuss some of the feedback we have received from the participants.

DESIGN PROBLEMS

The heading of this section may be read two ways: engineering problems involving design solutions that meet certain specifications, or problems that we have faced in creating the design criteria. Both interpretations will be discussed here.

The first three years

Consider the following general description of the first year's design problem. The objective was to automatically move a certain volume of material from one specified container to another identical container placed at some distance from the first, but at the same level. The score was simply the mass of the material transferred to the second container times the original separation distance of the two containers. However, if a full container of material was transferred the full distance possible in the allowed area, then a "time bonus" would be awarded. That is, the score would become mass times distance divided by the ratio of the time taken to the maximum time allowed (three minutes). All of the energy used to perform this task had to come from wind generated by an ordinary table fan (which we provided) positioned at one end of the allowed area. There were no constraints placed on the materials that could be used to construct the device. The only constraint on size was that the entire device had to fit inside a given area. Thus, we had an open-ended design problem that involved two primary systems; one to collect the energy provided by the wind, and the other to transport and deposit the material.

Now consider the features of this problem. The system was power driven, i.e. the fan ran at constant speed for the entire run time. The system was completely automatic once started (no team member was allowed to touch the device once the timing began). There was an obvious winning strategy, i.e. move the full container the full distance, and dump it into the destination container, as quickly as possible.

What did we observe? There were many different designs for the wind energy collection sub-system, although the most efficient appeared to be one that used a fan blade nearly identical to that of the table fan. There were two main approaches to transferring the material (as we expected). One was to simply move the first container filled with material, and dump it into the second container. The other was to use a conveyor system to continuously transport the material. Nearly all of the designs were of the first type, and all of the winning systems were of that type. The conveyors were uniformly wasteful of energy and material, were complex, and did not operate reliably. The bulk transport systems were simple and built for speed. The winning system deposited its material in just under twenty seconds (a factor of nine for the time bonus). We also observed, however, that these systems either worked, or they didn't. Scores were either very good, or zero. Six of the 28 teams scored zero because their systems did not work on either run.

How did the participants respond to this problem, and to the competition in general? We had 28 teams of two to five students each from a total of 14 schools at this first competition. Nine teachers and 39 students returned our survey forms. All of the teachers and all but one of the students thought it was a valuable educational experience and that the problem was at the right level of difficulty. With regard to the problem statement itself, about one-third of the teachers and students thought the rules could have been clearer and more precise. All of the teachers and all but three of the students found the competition enjoyable. 34 of the students said the competition helped them with understanding and/or appreciating science, mathematics, and technology. All of the teachers, and 12 of the 14 non-seniors who responded to the survey indicated that they wanted to participate again the following year.

Given the extremely positive response, we continued with the same format for the next two years, although the specific problems were different. In the second competition power was provided by batteries, and a certain mass needed to be raised to a certain height to obtain the time bonus. Here the energy was limited by the total capacity of the batteries, but it was essentially power-driven given the motors used. Here again, the winning designs were very similar, and speed was important. We changed to a primarily energy-limited source in the third year by specifying a certain mass of material starting at a certain height that could be dropped a certain distance. The energy was to be used, again, to transport some material from one location to another. Speed was again a prime consideration. Overall, the survey responses were very similar to those of the first competition, and the number of schools and teams participating increased each year.

The next three years

Given the success of the first three competitions, there were many reasons to leave the basic type of design problem unchanged. However, there were several issues that concerned us. Several teachers felt that the importance of speed was overemphasized. Concomitant with that the scoring formulas were very simple, and required little analysis. Basically, it was mass times distance (or height) divided by time. From our point of view, it seemed that most devices did not seem to be robustly designed. Since, in essence, a device only needed to do one thing once in two runs (although quickly) some teams seemed to be relying more on hope and luck to succeed. Thus, there were a fair number of zero scores. Also, we felt our scoring formulas were leading most teams toward one particular type of solution, rather than encouraging a variety of designs. Thus, we decided to make some changes to the type of problems we created, and try to introduce some complexity into the scoring calculation.

First, we decided to eliminate the time bonus to encourage devices that would operate continuously for the entire three-minute run time. We designed a problem that would encourage performing a particular task multiple times automatically, and added trigonometric and log functions to the scoring formula to encourage more analysis. We hoped this would have the additional effect of encouraging a wider variety of designs.

The fourth year's design problem involved automatically launching spherical projectiles toward a target area. The size and mass of the spheres were unspecified, and the score depended on both total mass and number of spheres launched. In addition, the height and distance were factored into the score. We also returned to a constant power source. The device was to be powered by specified solar cells, which we illuminated with ordinary floodlamps.

The results of these changes were positive. The teachers all thought the scoring formula, with no obvious optimal solution, was better than previous ones. They felt the analysis of the scoring formula was important to the design process and was relevant to the curriculum. We saw an interesting variety of very clever designs, and a range of strategies for maximizing the score. Although many participants indicated that this seemed to be a difficult problem, there were fewer total failures than in previous years. We decided to continue this type of design problem.

The fifth year's problem required student teams to design a device to automatically retrieve items located in an open area some distance from the apparatus. The score depended on the size, weight, and number of items retrieved, and the distance each item was moved, in a complex formula with no obvious optimal mix of items. The device was to be powered, again, by electricity. However, we chose to use a small hand-cranked generator as the power source. An individual team member would crank the generator. Although we didn't realize it at the time, this small change would signal a trend that has continued to the present competition. Previously, no team member had any contact or interaction with the device at any time during a run. Although this was still technically true, a team member was now actually providing the power for the device. Despite the fact that the generators turned out to be less than robust, and thus we eventually allowed most teams to use batteries as a substitute, we decided to try this approach again.

In the sixth year, all the power for the device was to be provided by one or two hand pumps. Also, for the first time we allowed control mechanisms to be operated by the team members during the run. The air-powered machine was supposed to move a variety of recyclable materials into specific recycling bins. The scoring formula was specified in terms of a profit based on number and type of recycled material, with waste and operating costs factored in.

The last three years

During the previous three years, we considered the complex scoring formulas to be essential components of the design problem. The teachers, in particular, appreciated this aspect of the problem. The students were more focused on building a device that worked, as opposed to one that worked optimally based on the scoring formula. However, the educational benefit seemed undeniable, since the analysis of the formula came first, and the practicalities of building the device came later. Nevertheless, the winning teams uniformly had a clear grasp of the contributing factors and their relative importance.

We also saw some benefit to the direct involvement of the team members during the running of their device. However, we wanted to avoid having the competition become a contest of skill rather than one of engineering design and construction. We decided that direct control of the mechanisms by team members was not a feature we wanted to incorporate. However, having the students provide their own power seemed to work well. It was fun to watch, and the students enjoyed it as well.

The seventh year's competition incorporated a student driven power source. The power was to be provided using a bicycle (or any part thereof) linked to the device. The design problem itself was basically an assembly line, which was to package several items in two different combinations. The formula was also described as a profit, where the profit of the two combinations was different and packaging errors counted against you. As an additional way to have team members involved without directly controlling the mechanism, we allowed one team member to do "quality inspection" at the end of the assembly line. The idea was that there was an optimal mix of correctly packaged items, but having a team member remove packages with the wrong combination of items might affect the ratio of correctly packaged items. It was not at all obvious whether it might be better to remove all, some, or none of the incorrect packages. The only obvious optimization was to have a device that worked perfectly for the entire run time. As it turned out, no team had a perfect device, but many had functional assembly lines (even if they only produced a few packages), and some had excellent understanding of the strategy involved in the quality inspection process.

The biggest problem we ran into during the seventh competition was a decrease in the number of participating schools and teams. This was a real disappointment. The reason apparently was the difficulty in building a working assembly line. Many students thought it was a very difficult project, and some teachers that did not participate told us that it was too hard for their students to build. We decided to try something different.

The eighth year's competition was basically a target shooting contest, but with a twist (or two). A ball was to be launched toward a target by dropping a specified weight from a specified height (a very simple concept). One team member would load the ball into the launcher, another would drop the weight, and another would retrieve the ball. Teams could launch the ball toward the target as many times as they desired in five minutes (increased from the three-minute run times of previous years). However, the scoring formula reduced the value of each launch until the target was moved to another position in a grid of allowed positions. Each team was provided with a randomized list of these positions before each run, and the target had to be moved (by another team member) to new positions in the order specified in this list. Different positions had different values, and accuracy counted as well. Thus, each team had to decide, as the run continued, how many balls to launch at a particular target location. Also, of course, the device had to be adjusted each time the target was moved. A fixed discrete amount of energy was available for each launch so the device had to account for this. There were a number of possible strategies. This competition directly involved team members in a direct way without relying on the skill of the team (except perhaps in retrieving the ball quickly). Also, very simple designs could have some measure of success. Winning teams combined excellent engineering with good strategy and teamwork. Many teachers, students, and spectators thought this was a great competition.

The ninth, and most recent, competition continued with a similar theme. Teams were required to roll different sized balls down a specified ramp into a circular area. The task was to launch another ball from outside the circular area so as to defect the rolling ball into the proper bin on the opposite side of the circle. The launching mechanism was to be powered by an unspecified source of stored potential energy (such as a compressed spring, stretched band, or lifted mass). Each launch had to be triggered by a battery powered mechanism triggered by the rolling ball traversing a photogate. Again, team members were kept busy rolling balls down the ramp, aiming and loading the launcher, and retrieving the balls. Scoring was based on how many balls of which type ended up in which bins. Again this year, the teachers and students responded very positively to the excitement of the competition because of the active participation of team members, and we were impressed with the number of successful designs and their variety.

SUMMARY

This paper has described the evolution of our high school engineering design competition over its nine years of existence. We have learned much about running such a competition, and we have made changes that we feel have continually improved it over the years. We now feel that the competition should have the following features:

- Design problems should have "minimal" solutions that are accessible to all high school students so that all can have the opportunity to have a successful design experience.
- Scoring should require some analysis, and should have no obvious optimal solution.
- Power sources should be strictly specified, and student-powered devices should be considered.
- Direct control of the device during competition may involve more skill than engineering, and probably should be avoided.
- Team members should be involved in the performance of the task in a way that does not detract from the engineering design.

Features that we have incorporated from the beginning that have been successful are:

- Required design previews and formal Design Portfolios.
- Score-based competition as opposed to head-to-head elimination tournaments.
- Open-ended design with little or no restrictions on the types of materials or devices allowed.
- Devices should be able to be constructed from readily available and inexpensive materials with simple hand and power tools.

REFERENCES

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[2] Vermont Department of Education, "Vermont's Framework of Standards and Learning Opportunities," 1996.