# The Pros and Cons of a Physics Design Competition: Perceptions of Students and Teachers

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## ABSTRACT

THE SHALHEVETH FREIER PHYSICS TOURNAMENT is a competition between five-person teams from various high schools. The students, who are physics majors, are invited to build safe-locking devices, based on their studies in physics, chemistry, electronics and computer sciences.

After building these devices, each team gains points by successfully breaking into the safes built by the other teams as well as by designing a lock which resists break-ins. In order to be able to break into safes built by other teams, the students must understand and apply relevant scientific principles and technological concepts.

The overall goal of the study was to identify the components of a good design competition, from the point of view of the participating students and their teachers. In order to address this concern, we posed the following research questions:

(1) What do the participating *students* perceive are the "contributions" and "costs" of the competition?

(2) What do the participating *teachers* perceive are the "contributions" and "costs" of the competition?

A questionnaire study was conducted on 72 students, out of 125 overall participants of one of the recent tournaments. We used closed as well as open-ended questions.

Based on an anlysis of the collected data, we propose that three major factors compose a good design competition: (1) a good balance between the competitive and social aspects of the competition, (2) a good balance between the challenge itself (intrinsic motivation) and prizes (external motivation), and (3) strong school support (financial, emotional and organizational) for the participating teachers and students

## RATIONALE AND BACKGROUND

Science and technology competitions offer students and their teachers multiple opportunities to engage in and learn about science and technology. However, despite the "tremendous growth" in such competitions in the past 50 years, "few formal evaluations have been conducted" (Somers and Callan, 1999). In this paper, we argue that evaluation and research efforts about specific science competitions can improve our knowledge base regarding the effectiveness of such competitions in science education and can help "bridge the gap between formal and informal science education" (Hofstein and Rosenfeld, 1996). Specifically, we suggest that such research efforts should focus, at least in part, on the perceived benefits and drawbacks of such competitions, from the perspective of two key stakeholders: students and their teachers.

In this paper, we present a short review of science competitions, a description of a specific science competition (The Shalheveth Freier Physics Tournament) and a study of this competition, focusing on the pros and cons of the competition, as perceived by the participating students and teachers.

### Review of Science Competitions

All science competitions seem to be based on any number of the following goals: generating enthusiasm for science, engineering and mathematics; encouraging careers in these areas; promoting and rewarding achievements in science and technology; promoting science or mathematics knowledge; developing research and problem-solving skills; understanding how real scientists and engineers work; integrating sciences across the disciplines; exploring future technology and using current technology (Somers and Callan, 1999).

According to Hughes (2000), an additional goal is to "provide an academic alternative to athletic competitions." This is one of the goals of the Science Olympiads, which were established in 1983. In other words, since modern society promotes and rewards student achievements in sports, it is also important to provide opportunities to promote and reward student achievements in science, technology and mathematics.

Somers and Callan (1999) identified more than 60 science and mathematics competitions in the United States and categorized them according to a taxonomy with the following categories: (1) type of competition, (2) content area, (3) grade level, (4) program goals, (5) screening, (6) number of participants, (7) product of competition, (8) judging criteria, (9) background of judges, (10) type and value of awards given, and (11) sponsors.

Some competitions are pencil-and-paper activities, some involve lab work and others require students to design and build artifacts. Pencil-and paper activities can be regarded as physically passive but mentally active types of participation, while competitions involving lab work and design activities can be both physically and mentally active.

It seems that science competitions naturally attract students of higher-than-average ability and/or motivation; they can also serve as a trigger to enhance interest in science among those who have the ability but little interest (Campbell, Wagner and Walberg, 2000; Hughes, 2000).

It also seems that participation in any science and technology competition can be a catalyst for leaning more about science and technology. A design competition, where participants are requested to plan and build a working model is one of the most challenging competitions, in that it requires combining skills of ingenuity and originality, motivation, commitment, research abilities, self-directed learning, planning abilities and teamwork. Struggling with the tasks, students have to research and solve problems, and thus develop abilities to work autonomously.

A design competition can also enable students to gain insights about their own abilities, in comparison with those of other participants (Campbell, et al., 2000). It can also reveal and develop science and technology abilities and skills that were hidden to teachers beforehand; through such a competition, teachers can discover that some students, who were not previously considered as "stars" in the class, are revealed as having exceptional skills in designing and building their projects.

Furthermore, an argument has been made that science competitions promote talent development in science. Sosniak (1999) suggests that the main components of talent development in the sciences are (1) student investment in time-intensive efforts, (2) student engagement in authentic tasks and (3) student involvement with communities of like-minded committed individuals. Science competitions can provide students – who are self-selected and volunteer to participate in such competitions – with opportunities to develop these three components.

In conclusion, it appears that few empirical studies exist regarding the impact and effectiveness of science and technology competitions. In particular, few studies explore the benefits and drawbacks of such competitions, from the perspectives of the participating students and teachers. If we could learn more about these perceptions, perhaps we could better understand what the components of a good design competition are. In the rest of the paper, we describe a specific science competition and present a study of its pros and cons, from the perspectives of participating students and teachers.

## The Shalheveth Freier Physics Tournament

The Shalheveth Freier Physics Tournament is aimed at students who are physics majors[1]. Teams of five students plan and build a lock for a safe based on their physics, chemistry, electronic, and computers studies. After building the locks, they gain points by successfully breaking into the safes built by the other teams as well as by having ingenious lock that resists break-ins.

At the beginning of the academic year, the interested students and their teachers are invited for a study day at the Weizmann Institute. On this day they are introduced to the tournament through a short video film of previous competitions and they learn about this year's project. They also receive the materials to build the safe: wooden boards for the box, a transparent door and an electrical lock, which can be opened when it receives an electrical current. The participants' task is to plan how to bring the current to the lock.

The students have about three months to plan and build the safes. During this period, the coordinators of the program (doctoral students in physics) accompany the teams and advise them when needed. The teams are invited to the Weizmann Institute

[1] At the Israeli high school system every student in $11^{th}$-$12^{th}$ grades is required to major in a certain subject, either from the humanities or from the sciences disciplines. Those who choose physics are also required to choose a high level of math. Shalheveth Freier (1920 -1994 ) was a physicist who made significant contributions in many fields, including the initiation and organization of Israel's first hi-tech industrial park (Freier, 1986).

of Science to the two-day tournament. Each safe.(see the appendix for two examples) is put in a separate room, and four members of a team, accompanied by a graduate student of the Institute, try to break into the safes of their peers within a time interval of 10 minutes per safe. Each team attempts to break into the other teams' safes. The fifth member stays with the team's safe and is responsible for resetting the lock for the next team and for explaining how the lock works. The role of the escorting graduate students is to make sure that the teams work according to the rules in their attempts to break-in and to keep the time intervals. Each team's relative success at breaking into the other teams' safes is translated into 15% of each team's total mark.

Prominent professors of the Physics Faculty volunteer to serve as referees. Moving from one safe to the next, they evaluate the following criteria: (a) the sophistication and creativity of the idea underlying the specific locking mechanism , (b) the elegance in the project's implementation, the (c) the functional performance and appearance of the exhibit, and (d) the students' scientific comprehension of the specific locking mechanism. The referees' grade is calculated as 55% of each team's total mark. The final mark of each team is a weighted average of the referees' grades (55%), the grades given by all other teams (20%), the number of successful breaks-in (15%) and the number of teams who fail to open the safe (10%).

The tournament's second day is devoted to an exhibition of all participating safes. Each team demonstrates its own invention to fellow participants, parents, teachers, friends and curious Weizmann Institute members. This happening is concluded with a ceremony and the announcement of the winning teams.

Each year a booklet is issued, describing the various safes and their locking mechanisms. The booklet also contains detailed explanations of some locking mechanisms and links to relevant literature, mainly on the Internet.

The Ministry of Education gives financial support for the competition and the winners receive a grade of 100 points for the matriculation examination in the physics lab. About 50% of the teams receive prizes.

The major focus of the competition is for the participating team members to devote their time and talent to the design and building of their inventions. The students need to think of possible locking mechanisms, to select the most appropriate one and to ascertain the feasibility of its implementation; occasionally they need to build a simplified model. Next, they need to calculate the optimal parameters of all the locking apparatus components, and to build the safe. Finally, they have to test the safe under normal conditions, to guarantee its robustness and to assure an overall respectful appearance. The participants are thus exposed to the entire process of inventing and building a device based on principles of science and technology

In summary, the Shalheveth Freier Physics Tournament can be described by using the taxonomy and categories of Somers and Callan (1999); in two cases, we had added a new and more appropriate category ("new category"):

(1) Type of competition: combines characteristics of both a competition and a fair,
(2) Content area (physics, engineering and electronics),
(3) Grade level (high school),
(4) Program goals (Generate Enthusiasm for Science, Engineering and Mathematics; Improve Research Methods or Problem-Solving Skills; Understand How Real Scientists and Engineers Work),
(5) Screening (requires project teams to present specific proposals),
(6) Number of participants (200-499),

(7) Product of competition (Description of Design, Actual Design)
(8) Judging criteria (Ingenuity, Creativity, Innovation; Workability, Effectiveness Performance of Design; Craftmanship; Student Interest in Science and Math)
(9) Background of judges (Science, Engineering, Industry Professionals; Educators; Local Teachers)
(10) Type and value of awards given (Certificates to All Entries; new category: team prizes of $1,000, $750 and $500 to cover building costs; new category: grade of 100 for the matriculation examination for physics laboratory work),
(11) Sponsors (University).

## The Study

### Research Questions and Methodology

Our overall goal was to identify the components of a good design competition, from the point of view of the participating students and their teachers. In order to address this concern, we posed the following research questions:

> (1) What do the participating *students* perceive are the "contributions" and "costs" of the competition?
>
> (2) What do the participating *teachers* perceive are the "contributions" and "costs" of the competition?

Regarding the students, we designed a student questionnaire to help us identify the perceived contributions and costs of the competition and understand the relative strengths of these contributions and costs. We used both (a) close-ended questions and open-ended questions. (See the appendix for details.)

(a) Close-ended questions. We developed and administered a questionnaire to 72 students, out of 125 overall participants of the 2001 competition. This questionnaire included 23 close-ended questions which explored the student perceptions of the contributions and costs of the competition. We analyzed the student data for the close-ended questions by calculating averages of the Likert scales.

(b) Open-ended questions. These questions, also part of the questionnaire, were based on the PMI (Plus, Minus, Interesting) strategy of deBono (1968). We asked students to list “positive aspects,” “negative aspects” and “interesting aspects” of the competition. We categorized each written comment according to categories which emerged from the analysis. In this manner, we generated a list of categories and sub-categories. In order to receive a measure of relative strengths of these categories, we calculated the percentages of responses for each of these categories.

Each comment was recorded separately; for example, if a student’s open-ended answer comment included two different categories, we counted each of the two different responses, one for each category. As a result, we calculated percentages of the total responses, which was different from the number of students in the sample. In our analysis, the answers for "positive aspects" and "interesting aspects" were collapsed together and considered as contributions.

Regarding the teachers, we interviewed 5 out of the 20 participating teachers in the 2001 competition, using a structured open-ended format. We asked the teachers to describe what they considered to be the contributions and costs of the competition, from their point of view. In addition, the teachers were given the same open-ended questions as the students, as described above.

In the following sections, we report our findings first from the perspective of the participating students and then from the perspective of the participating teachers.

## Findings

In this section, we report the results of our study, first regarding the perceptions of the participating students and then regarding the perceptions of the participating teachers.

### <u>Perceptions of the Students</u>

#### What do the participating students perceive are the "contributions" of the competition?

Part of the answer to this question is presented Table 1, in which the students scores from the questionnaire are *ranked from the highests to the lowest* results (on a 4-pt.scale). The data show that most significant "contributions" for the students, from their point of view, relate to the (a) ***design experience***, (b) ***resulting skills*** which were developed (c) the ***resulting affective benefits*** and (d) ***social benefits***. The value of the design experience includes understanding that there is a significant difference between theory and practice (#1) and that the experience itself is good to have(#2). The resulting skills include the development of creativity (#3), problem-solving (#5), research skills (#7) and teamwork (#11). The resulting affective benefits include developing the feelings of personal satisfaction (#4), interest in physics (#6), responsibility (#8), and self-confidence (#10). The social benefits include the connections created between students (#9) and development of teamwork (#11).

A surprising result is that "understanding that there is a difference between theory and practice" is seen by the participants as the most important contribution of the competition (#1).

The students perceive much less value of the competition in improving their grades (#12) and understanding the work of the scientist (#13). Their lowest average score is for the statement that participation in the competition "improves students' performance in the physics lessons (#14).

--- Place Table 1 around here –

In contrast to their perceptions regarding the contributions of the competition to themselves, when the students were asked about what the competition contributes to the school, they were much less enthusiastic, as can be seen in Table 2, where all of the average scores are below 3.0; their lowest scores related to the effect of the competition on science teaching in the school (#5) and improving the school's atmosphere (#6).

---- Place Table 2 around here ----

A second way to understand student perceptions of the competition's contributions is to analyze the results of the open-ended question "to list the positive and the interesting aspects of the competition." (See Table 3.) During the process of categorizing 146 students responses, 5 categories and 14 sub-categories emerged. Note that the most popular and diversified category involved Motivational Aspects (36.3% of all responses), followed by Cognitive Aspects (18.8%), Social Aspects (18.8%), and Creative Aspects (10.0%).

--Place Table 3 around here --

Below are some examples of the types of statements made for each of the categories listed in Table 3.

<u>Social Aspects</u>
Group Work
"It's interesting to work with other team members."
Meeting Others
"You get to meet fellow students from all over the country."

<u>Cognitive Aspects</u>
Learning Physics
"It helped us learn physics."
New Learning; Non-conventional learning; Self-Directed Learning
"It helped us learned new things and open our horizons.

<u>Creative Aspects</u>
Development of Thinking and Ideas; Creativity;
creative thinking; problem-solving
"The competition caused us to open up our minds."
"The competition helped us develop thinking skills."
"It contributes to amplify our creativity and develop our thinking."

<u>Practical Aspects</u>
Connecting Theory to Practice
"It helped us develop the connection between the theoretical and practical aspects of physics."
"It helped us look at physics from the practical aspect."
"We understood the gap between theory and practice."
Process of Building
"We were able to use equipment we normally don't use in school."
"The process of building develops interest in physics."
Process of Breaking-In
"It's the greatest feeling in the world to open someone else's safe and not

have them open yours!"

Motivational Aspects

Motivating, challenging, develops curiosity; interest; develops ambition

"Physics is presented in an interesting, entertaining and challenging way."

"In every safe there were interesting aspects."

"Working on the safe was more interesting than learning physics in school!"

Prizes and competition

"I liked getting 100% on my physics lab grade."

"You have the chance of getting a prize."

Fun

"It's fun to break into the safes that other teams built."

Personal responsibility

"Despite all of the difficulties, we were able to succeed."

Development of Interest in Science

"The competition develops student interest in science."

**Comparison of Open-ended with Close-ended Questions**

In comparing the findings from the two types of questions, we see that there was an overlap between all of the categories which emerged from the open-ended questions with items in the close-ended questions. In order of the student ranking, the questions related to Practical Aspects (#1, #3), Creative Aspects (#3, #5), Cognitive Aspects (#7), Motivational Aspects(#2, #4, #6, #9, #8) and Social Aspects (questions #10, 14)

The results from both the close-ended and open-ended questions also show that the students learn teamwork and value the social benefits of the competition. They valued working together as a team. About 70% of the participants agreed that going through the planning and building process improved their cooperative skills, and about 80% thought the competition improved their social connections at school. Many students referred to the social aspects of the whole process and the atmosphere at the Weizmann Institute during the competition, as a very enjoyable event. "The building process is fascinating and so is the competition. You meet youth from all over the country" or "Meeting with students from all over the country and building the safe is very enjoyable".

On the other hand, there were topics addressed in the close-ended questions which did not appear in the open-ended questions. These close-ended questions dealt with the work of scientists (#12), the effect of the competition on learning physics in school (#11, #13) and the effect of the competition on the development of school pride (#15).

**What do the participating students perceive are the "costs" of the competition?**

The results of the close-ended questions are presented in Table 4. Close to 90% of the students agreed that their participation in the competition “burns up a lot of time” (#1). However, only about 30% felt that the competition caused students to neglect their studies in other disciplines (#2) and less than 15% felt that their participation distracted them from learning physics in school (#3).

-- Place Table 4 about here –

Other data relating to perceived student costs comes from an open-ended question in the questionnaire as illustrated in Table 5. During the process of categorizing 67 responses from the 71 students, we found that 22% the students gave no negative comment. Regarding the other responses, 5 categories and 11 sub-categories emerged. The most common negative comments involved issues relating to the competition (24%), i.e., not enough prizes, the disappointment of not winning, too much adult involvement, etc. The next most common “cost” category involved technical issues involving the safe (19.5%), followed by organizational problems (15%), time problems (13%) evaluation (3%) and financial cost (1.5%).

-- Place Table 5 about here --

Below are some examples of the types of statements made for each of the categories listed in Table 5.

**The Safe**

Irrelevant “Tricks “

“Some of the safes used gimmicks.”

Multiple principles of physics involved

“There were schools which built safes which were based on principles not taught in physics but rather in other disciplines, such as chemistry and electronics. As a result, we lacked the necessary information needed to break into the safes.”

Difficulty level too high; need to limit physics principles

“I think you should limit the students from using complicated physical principles, that aren’t known to many of the other students.”

Ideas not original

“The ideas are copied and repeat themselves from year to year.”

Safes were physically broken

“Some students physically broke the safes, and this was disturbing.”

**Evaluation**

Lack of standard grading criteria

“The judging was arbitrary.”

**Competition**

Too much adult involvement

"In some cases, there was too much involvement of the teachers in building the safes."

Background levels of the participants not equal

"There are differences in the levels of different schools."

Not enough prizes; it's disappointing when you don't win

"There's a problem when a student can work very hard on a project and in the end not receive anything for his efforts."

"The project takes time and students are discouraged when they don't win."

Size of team too small

"Limiting the team size to only 5 students is a problem."

Unfair practice: teams tell others how to unlock safes

Too much of a competitive atmosphere

"There was too much of an atmosphere of competitiveness to win prizes. You should give prizes to every participant!)"

**Time**

Took too much time; students neglect their studies because of time pressures

"The project took a lot of time. It was very difficult to combine working on the project with working on our school studies."

"Some of us missed important physics lessons in school, in order to work on the safe."

**Financial Cost**

Cost too high

"Sometimes students need to spend a lot of their own money on building the safes."

**Organization and Management**

Organization problems; problems relating to staff, schedule, space

"Sometimes there was a bottleneck, when one group took too long to open a safe."

"There was a lack of organization when the teams had to open the safes."

"Not enough time given to open the safes."

In addition, in responses to another open-ended question, students were asked to respond to the issue of school support. Several categories of organizational support from the participating schools emerged. These categories – and examples of student responses -- follow:

(1) Time.

"When we wanted to take time from our classes and use it to work on our projects, not all of the teachers would agree to cooperate." (1)

(2) Equipment.

"The school helped us gain access to use the advanced equipment we needed."

"The physics and chemistry labs in the school were not helpful."

(3) Financial assistance.

”… there was a serious lack of funds.”

"The administration of the school didn't really care about us. They promised us they would cover our costs and asked us to give them our receipts. We'll see if they keep their promise."

(4) Mentoring.

“The teachers gave us advice only in terms of theory.”

“ Our teacher didn’t really help us.”

(5) Encourgement.

“Encouragement was good for my morale…”

"The school gave us lots of support. They even gave us food when we stayed late!”

**Comparison of Open-ended with Close-ended Questions**

In comparing the findings from the close-ended and open-ended questions which related to the “costs” of the competition, we see that there was an overlap between only one of the categories which emerged from the open-ended questions with items in the close-ended questions, i.e., time (questions #1 and #2). The other categories which emerged from the open-ended question – competition, technical issues involving the safe, organizational problems, evaluation and financial cost – were not represented in the close-ended questionnaire. In regard to these categories, comments relating to costs involving “competition” were the most frequent.

**<u>Perceptions of the Teachers</u>**

**What do the participating teachers perceive are the "contributions" of the competition?**

Because we had a small sample size of participating teachers (N=5), we will present the teachers' perceptions of the contributions and costs of the competition in qualitative terms, based on our interviews and the teachers' written responses to our open-ended questions.

The participating teachers felt that the competition had a variety of benefits for themselves and their students. For themselves, they felt that the competition helped them in their teaching work, i.e., in motivating their students (and not only the participating students), in teaching physics and in developing better relationships with their students. The teachers felt that the competition helped their students develop their independent thinking skills, their motivation to study physics and their knowledge of physics topics that were not in the standard curriculum.

- The contact between teachers and students is strengthened; it becomes more open and spreads among all the science students.

- The intensive mutual work deepens the personal contacts within the Teaching staff.

- Discussing the project to all the students in the school adds color and excitement to physics and contributes to the popularity of science studies at the school.

- The project work strengthens the cooperation among the science teachers and the lab assistants.

- Science students, their teachers and lab assistants share the sense of creating something new in the school; the atmosphere of excitement mutual help adds a lot to the school.

For example, one of the teachers whose students have been participating in the Physics Tournament for the last three years:

> *"For me, it is a physics festival, a pure enjoyment for me and my students. For the last three years I found out that students who are* not *considered as the stars, are very creative and develop new knowledge in physics. I learned to know my students differently and that makes it worth it all. The competition provides the students with very different opportunities than school does."*

The project could not be successful without the support of the school management and at least one science teacher at the school. We found that many teachers used the project as a trigger to advance science education. For example, in the northern part of the country, where the students live far a way from an academic institution, student participation in the project had a strong effect on raising interest in learning physics. The lead teacher used the competition to motivate and engage his students. Every year, even before choosing the center's teams for the next competition, the teacher gathers many students together and asks each one to study the published designs of one of the previous years' safes. The students are asked to present these safes to the class, to explain how it was planned and built, and to suggest the best way of breaking into it. According to the teacher, this exercise gives the students a good understanding of the scientific laws of the previous projects, develops their thinking skills and motivates their learning of physics.

**What do the participating teachers perceive are the "costs" of the competition?**

Time represented the biggest cost, from the perspective of the teachers. We interviewed several teachers who had participated in previous years but had decided not to participate again, due to this factor.

Student disappointment in not receiving adequate recognition was another concern of the teachers. Some teachers said that there not enough prizes to justify the students' hard work. As one teacher wrote:

*"I think that the more prizes, the better. In the three years that I have participated, I have seen dozens of the most impressive projects ( the locking devices for the safes) and only a few won prizes. A large number of prizes doesn't decrease the status but it can greatly influence the motivation of students to participate in the coming years."*

A significant cost of the competition, from the point of view of the teachers, was the lack of support from their schools. We found that such support could "modulate" the overall "balance sheet" of the perceived contributions and costs of the competition. In other words, where there was adequate or exceptional organizational support, the perceived "costs" of the competition were lessened. On the other hand, the opposite was true: lack of support lessened the perceived contributions of the competition.

## SUMMARY AND DISCUSSION

A summary of the contributions and costs of the The Shalheveth Freier Physics Tournament appears in Table 6. In the following paragraphs, we will discuss these findings, relating them to our research questions, as well as the relevant literature, and will suggest implications for educational practice and further research.

-- Place Table 6 about here --

In analyzing Table 6, it is clear that both the participating students and teachers perceived that the design competition made contributions to the students in the areas of developing their skills and abilities (cognitive, practical and creative); increasing student motivation, excitement and science learning; and providing social interaction (within each team, between the participating teams and between students and teachers). In addition, the teachers felt that the competition also contributed to enhanced staff relations and enhanced professional and personal satisfaction. On the negative side of the balance sheet, both the participating students and teachers agreed on three major “costs” of the competition, i.e., issues relating to time, competition and the lack of school support.

On the positive side of the balance sheet, the students’enjoyment seems to be a product of the challenge they successfully met; we might say that the greater the challenge, the greater the student enjoyment in meeting it. Also, the students’ understanding of the difference between the theoretical and practical aspects involved in building the safe represent a significant stage in the “scientific maturity” of these students.

The findings, which relate to what the students perceive as "contributions" of the design competition, support similar educational research. For example, in other research (Hughes, 2000), when students were asked why they participate in science olympiads, they claimed that the experience provided them with a way to pursue their interests in science, provided them with “a sense of personal achievement” and a “feeling of belonging” to a team of peers with similar interests, gave them opportunities for learning topics of their interest and showed the relationship between book-learning and the real world.

In our study, both teamwork and social aspects of the design competition were valued by the participating students. These findings are similar to the findings of other studies of science competitions which show that “participants enjoy the teamwork aspects” of the competitions (Somers and Callan, 1999, p. 19). In a study similar to ours (Baired, 1996), it was empirically found that "team competitions place participants in situations where success depends on cooperation within a team while competing against other teams." It is worth noting that such cooperation within a competition has been shown to promote problem-solving performance (Johnson, Maruyama, Johnson, Nelson & Skon, 1981). Shaw (1932) found that even when there is unequal participation by members of the group, the groups hold significant advantage over individuals in a problem-solving situation. Johnson et al. (1981) conducted studies on individual, competitive and cooperative learning. They found that cooperative learning is superior in promoting achievement over all age levels within science. Hughes (2000) also reported the advantages of teamwork, such as: (1) developing cooperative skills, (2) belonging to a group of peers with similar interest and abilities, (3) actively learning the subject they chose, collectively, (4) developing local pride, and (5) bringing an idea to a working model, thus deepening the students’ understanding much more than what is achieved by preparing for an examination.

In our study, the participating students reported that the competition gave them many benefits which go beyond traditional school learning. For example, as demonstrated in the analysis of the close-ended questionnaires (Table 1), one of the most significant contributions of the competition, as assessed by the students, was helping them to "understand that there is a difference between theory and practice." What do they mean by this?

In schools, physics is taught in “idealized conditions” which neglect everyday practical aspects. For example, when learning about mechanics (e.g., the movement of a pendulum), friction is ignored. When learning energy transformations, the effect of heat loss is minimized. However, when engaged in practical work, students realize that such factors cannot be neglected and must be taken into account. Also, high on the students’ list of contributions was the statement that the "challenge of building a working device leads students to be creative." These are benefits not normally part of the formal school science curriculum and point to one of the reasons why design competitions within informal contexts can contribute to science learning in schools.

Along with considering these benefits, it is important to address what students and teachers agreed to be the three negative factors associated with their participation in the competition. First, students and teachers agreed that issues relating to time were significant. In order for the students and teachers to successfully design and built a unique safe, they had to make significant time commitments. Second, students and teachers were concerned with issues relating to the competition itself. For example, a major concern was that many students did not receive the recognition they deserved for their work. Third, both students and teachers were concerned about the lack of school support. Students complained that they lacked adequate school-based time to work on their projects as well as appropriate equipment, financial assistance, mentoring and encouragement. Teachers often felt that they lacked tangible support, and encouragement their schools.

This latter point cannot be underestimated. Only a small number of student teams functioned without teacher support. In our study, teacher support was the “key to success.” But who supported the teachers? Unfortunately, the participating teachers felt they were not given adequate encouragement, incentives and recognition for their work. In some cases, the teachers were self-motivated enough to continue without this support. In other cases, we suspect, the lack of such school support led to teachers dropping out of the competition.

This “drop-out phenomenon” is illustrated by group data from the physics competition reported in this article, which plots two graphs: the number of student groups which started and the number that finished building their projects during a five-year span (Fig. 1). These graphs show that the competition increased in popularity, over time. In 2001, 36 student groups started building safes and 25 student groups completed them. In contrast, by 2005, 105 groups started, and 50 teams finished (including three international teams). Note how the difference between the two graphs (an expression of the drop-out phenomenon) increases.

This drop-out phenomenon is worrisome. Of course, the lack of school support for teachers and students is only one possible contributor to this phenomenon. Other possible factors, such as adequate support from the hosting institution and student commitment to the competition, also need to be considered. We raise the issue of this phenomenon because we feel it relates to the overall question of what makes a good design competition.

Based on our study, we propose that three major factors compose a good design competition. First, there needs to be a good balance between the competitive and social aspects of the competition. For the students, the social aspects (relationships between the group members, students and teachers, as well as students from different schools) were very important. In the Physics Tournament reported here, the actual competition itself had a very strong social component; for example, students competed in groups against each other, but also participated in a fair, a social evening and in other social activities, where they had opportunities to get to know each other. It is interesting to note that good scientific work is often based on a good balance between a competitive drive and a good social collaboration between the scientists themselves. In our study, the students did not agree with the statement that the competition helps them “understand the work of the scientist,” and yet social aspects – which the students enjoyed – are a defining aspect of good scientific work.

Second, we believe that a good design competition should include a good balance between the challenge itself (intrinsic motivation) and prizes (external motivation). On the “intrinsic” side of the balance, it is important to choose a design challenge which is both engaging and realistic; we believe that the study shows that the challenge of designing a safe, using scientific principles, fits these criteria. On the “extrinsic” side, care should be taken that good student work is adequately recognized. Prizes confirm to the winning students that it was worthwhile for them to engage in the project. However, many students who do not win prizes can justifiably feel slighted by not receiving formal recognition. In other words, if significant ability and effort need to be applied in order to successfully complete the design challenge, a diverse and adequate number of prizes should be included.

Third, as mentioned above, a necessary component of a good design competition is school support for the participating teachers and students. Such support should include financial support (e.g., for equipment and travel), emotional support (e.g., encouragement from the school administration) and organizational support (e.g., opportunities for students and teachers to work together in the school).

In other words, if the school administrations were to provide teachers with dedicated hours to work with student groups, and even to provide them with small budgets for purchasing necessary materials for the projects, we believe that many more students groups would have participated in the competition and successfully completed their projects. Our study also showed that many of the participating teachers used the competition to raise the level of physics learning in their schools, to create better relationships between teachers and their students – and these are significant contributions of the competition, which cannot be ignored.

It is important to note that, as a result of conducting this study, several changes were made in the Shalheveth Freier Physics Tournament itself. For example, as a result of the results reported here, the competition's management decided to improve the competition in the following ways: (1) the judging criteria were made more explicit, (2) a teacher was added to the judging team, (3) more prizes were added (from about 30% of the total participants to about 50%), and (4) the timetable for the competition was expanded, so that the participating teams would have more time to work on their projects.

Our study of the Shalheveth Freier Physics Tournament focused on what students and teachers perceive to be the pros and cons of a physics design competition. As described above, we believe that this perspective can better help us understand such competitions and better use them to blend together science learning experiences that occur in both formal and informal contexts. For example, the study shows that students and teachers thought that the Physics Tournament helped the students learn new knowledge in science and technology; develop practical skills, while connecting theory to practice; and engage in creative problem-solving. The study also shows that these benefits, gained in an informal context, were applied by some teachers to improve science teaching in a formal context. Just as the learning of design-based science can lead to the transfer of design skills to real-world settings (Fortus et al., 2005), so might out-of-school design competitions lead to the transfer of design skills to science learning inside the classroom.

## References


Baird, W., Shaw, E.L. & McLarty, P. (1996). Predicting success in selected events of the Science Olympiad. *School Science and Mathematics*, 96, 85-93.

DeBono, E. (1968). Five Day Course in Thinking. New York: Penguin Books.

Campbell J. R., Wagner H., Walberg H. J. (2000). Academic Competitions and Programs Designed to Challenge the Exceptionally Talented. In: Heller K. A., Monks F. J., Sterenberg R. J., and Subotnik R. F., (Eds.) *International Handbook of Giftedness and Talent, 2nd Ed*. (pp 523-535). Pergamon Press.

Feldhusen J. C. (1986). A conception of giftedness. In: R. J. Sternberg & J. E. Davidson (Eds.) *Conception of Giftedness* (pp. 112-127). New York: Cambridge University Press.

Fortus, D., Krajcik, J., Dershimer, R.C., Marx, R. W., Mamlok-Naaman, R. (2005). Design-based science and real-world problem-solving. *International Journal of Science Education*, 27 (7): pp. 855-879.

Freier, S. (1986). Parks of science-based industries in Israel. *Technovation*, 4:183-187.

Hofstein, A. and Rosenfeld, S. (1996). Bridging the gap between formal and informal science learning. *Studies in Science Education*, 28: 87-112.

Hughes, M. (2000). The impact of science Olympiad at a small magnet schools in rural Georgia. *Paper presented at NARST annual meeting, New Orleans, April 2000*.

Johnson, D. W., Maruyama, G., Johnson, R., Nelson, D., & Skol, L. (1981). The effect of cooperative competitive and individualistic goal structure on achievements: A meta-analysis. *Psychological Bulletin*, 89, 47-62.

Magen, E. (1998) The Safe Project: a trigger to upgrade the physics studies in high school. In the *Proceedings of the National Physics Teachers,* Kfar-Batya (16.12.98), pp.27-28. (Hebrew)

Olson, L. (1985). The North Dakota Science and Engineering Fair-Its history and a survey of participants. Unpublished manuscript. North Dakota State University, Fargo.

Pyrit, M. C., Talent Development in Science and Technology, in International of *Handbook Giftedness and Talent*, 2nd. Edition, K. A. Heller, F. J. Monks, R. J. Sternberg, R. F. Subotnik, Editors-in-chief, Pergamon, (2000). Pp. 427-437.

Renzulli J. S. The three-ring conception of giftedness: a developmental model for creative productivity. In: R. J. Sternberg & J. E. Davidson (Eds.) *Conception of Giftedness* (pp. 53-92). New York: Cambridge University Press.

Shaw, M. E. (1932). A comparison of individuals and small groups in the rational solution of complex problems. *Journal of abnormal and social psychology*, 44, 491-504.

Somers, L. and Callan, S. (1999). An examination of science and mathematics competitions: Report for the national science foundation.  Unpublished paper. Internet address: www.wmich.edu/evalctr/competitions.html

Sosniak, L. (1999). An everyday curriculum for the development of talent. *Journal of Secondary Gifted Education*, 10, 166-172.

Subhi. T.and Maoz. N. (2000) Middle-East Region: Efforts, Policies, Programs and Issues. In: Heller K. A., Monks F. J., Sterenberg R. J., and Subotnik R. F., (Eds.) *International Handbook of Giftedness and Talent, 2nd Ed*.  (pp 737-750). Pergamon Press.

Tannebaum, A. J. (1986). Giftedness: a psychological approach. In R. J. Sternberg & J. E. Davidson (Eds.) *Conception of Giftedness* (pp.21-52). New York: Cambridge University Press.

## APPENDIX: Two Examples for Prize-Winning Safes in the Competition

### I. The Aircraft Safe (Ort Brauda, Carmiel; 2000 winners)

**Principles:**

1. **Magnetic inductance**: When a loop of a conductor turns within constant magnetic field an alternating current is induced by the varying magnetic flux passing through its area. Electric generators, as small as that of bicycle and as big as huge turbine, make use of this well-known phenomenon.

2. **Earth magnetic field**: The Earth core is primarily made of melted iron. Due to the iron magnetic properties, and in spite of being in liquid state, it creates a residual magnetic field on earth. Its poles nearly coincide with, precessing slowly about those of our rotating globe. The Earth magnetic field is strong enough to orient the needle of a compass.

3. **Resonance:** To open our safe one has to generate alternating current at the resonance frequency of the "aircraft"-and-spring pendulum.

Since no alternating field generator is provided with the Safe, one has to generate it by creating a loop out of the external wire provided by plugging it to the input contacts, and turning the wire, just like jumping rope. The periodically varying Earth magnetic field flux generates the desired alternating current. The current is than amplified by a built-in amplifier and transduced to periodic up-and-down motion of a piston, which in turn push and pull the spring via a pulley. When the frequency of these vibrations coincides with the resonance frequency of the spring-"aircraft" pendulum the amplitude of the pendulum increases until it hits the switch and the lock is open.

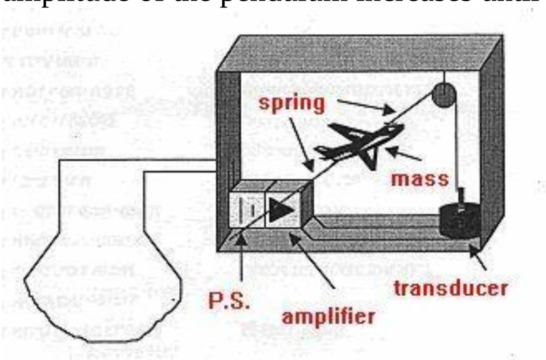


**Figure 1: Scheme of the Aircraft Safe.**


**Figure 2: Photograph of the Aircraft Safe.**

## II. The Pencil-Box Safe  (De-Shalit High School, Rehovot; 2001 winners)

In this project, the safe-locking mechanism is based on items found within student's typical pencil box.

<u>Principles:</u>

1. Radiation emitted by electric charge: When charged particle is accelerated an electromagnetic radiation is emitted. If this acceleration is periodic the radiation has the same frequency. In a typical calculator electrons are accelerated at the frequency of its clock all through its electric circuits, giving rise to RF radiation.

2. Change of polarization by reflection: The polarization of light is defined as the direction of its electric field vector. One may always define two orthogonal polarization directions in the plan perpendicular to the light direction. When light is reflected from a surface the two polarization components typically are reflected with different efficiency. For some angles the reflected light is predominantly made of one component only, hence it becomes polarized.

3. LCD display: LCD displays, such as that of calculator, are made of pixel matrix. Each pixel is made of liquid crystal, which changes the polarization according to the strength of the applied electric field. To display the desired monochromatic image the display is illuminated by polarized light and an electric field is applied to the appropriate pixels. The polarization plane of the light reflected from these pixels turns. The light is than reflected back through a polarizer transparent only to the unperturbed component. Hence, pixels subject to an electric field remain dark, thus generating the desired image.

To open the safe one should follow three steps using objects found in a typical high-school student pencil box (all are provide with - but outside - the safe).

1. Close the electric circuit by a pencil. To this end one has to sharpen both ends of the pencil and place it in the gap between both contacts (cf. figure). Its central part is made of carbon, which is known to be good conductor.

2. Using the calculator one may generate electromagnetic waves by hitting some keys. Placing the calculator outside the transparent door next to the receiver, the received radiation is amplified and the generated current opens electromagnetic switch.

3. The polarizer of the calculator within the safe has been removed. Hence the number on its display cannot be directly seen. This number is the code of the mechanical lock attached to the door of the safe. To read the display one should use the plastic ruler. Placing it (outside the transparent door) at the appropriate angle the reflected image of the display is polarized and the number can readily be recognized.

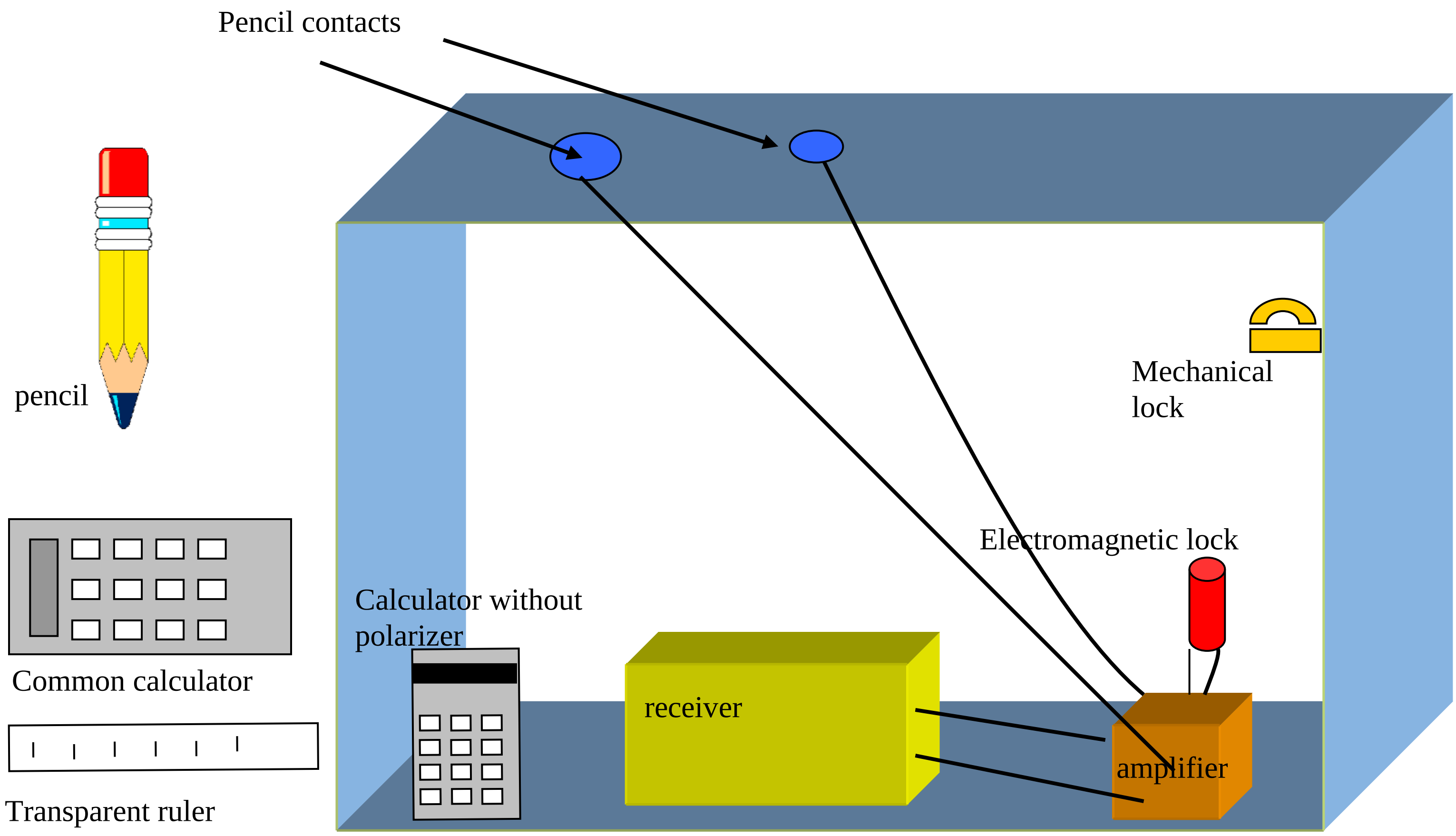


**Figure 3: Schematic diagram of the Pencil-Box Safe**

## Tables and Figures

Table 1. Student Responses: "What does the participation in the competition contribute to students?" (N=72)

| Average | Definitely Don't Agree | Don't Agree | Agree | Agree A Lot | Statement |
|---|---|---|---|---|---|
| 3.66 | 0 | 2 | 20 | 49 | 1. Students understand that there is a difference between theory and practice. |
| 3.63 | 1 | 0 | 23 | 47 | 2. The experience is good to have. |
| 3.54 | 0 | 3 | 31 | 38 | 3. The challenge of building a working device leads students to be creative. |
| 3.46 | 0 | 4 | 30 | 37 | 4. Students gain a feeling of personal accomplishment. |
| 3.32 | 0 | 7 | 34 | 30 | 5. Students develop skills in problem-solving. |
| 3.30 | 0 | 7 | 36 | 29 | 6. Students develop interest in physics. |
| 3.18 | 0 | 11 | 36 | 24 | 7. Students develop research skills. |
| 3.04 | 0 | 18 | 32 | 21 | 8. Work on the project develops in students the feeling of responsibility. |
| 3.04 | 1 | 11 | 43 | 16 | 9. Improves the social connection between students. |
| 2.97 | 5 | 29 | 30 | 7 | 10.Students develop self-confidence. |
| 2.97 | 2 | 17 | 33 | 19 | 11. Students develop skills in teamwork. |
| 2.78 | 0 | 22 | 39 | 11 | 12. Students improve their grades in physics. |
| 2.48 | 7 | 30 | 27 | 7 | 13. Students understand the work of the scientist. |
| 2.15 | 11 | 40 | 18 | 2 | 14. Participation improves students' performance in the physics lessons. |

Table 2. Student Responses: "What does the competition contribute to the school? (N=71)

| Average | Definitely Don't Agree | Don't Agree | Agree | Agree A Lot | Statement |
|---|---|---|---|---|---|
| 2.97 | 2 | 17 | 33 | 19 | 1. Develops school pride. |
| 2.89 | 2 | 20 | 33 | 16 | 2. Brings honor to the school. |
| 2.69 | 8 | 18 | 33 | 12 | 3. Improves the connection between good students from the school with others like them in other schools. |
| 2.54 | 9 | 27 | 23 | 12 | 4. Improves the connection between the students and the teacher. |
| 2.16 | 17 | 30 | 19 | 5 | 5. Gives rise to a higher level of science teaching in the school. |
| 2.01 | 18 | 37 | 13 | 3 | 6. Improves the school's atmosphere. |

Table 3. "What Were Positive Aspects About the Competition?"
Categorization of the Student Open-Ended Reponses (N=146 comments of the 72 students).

| **Percentage of Responses** | **Response Sub-Categories** | **Reponse Categories** |
|---|---|---|
| **18.8** | | **Social Aspects** |
| 6.7 | Group Work | |
| 12.1 | Meeting Others | |
| **18.8** | | **Cognitive Aspects** |
| 7.4 | Learning Physics | |
| 11.4 | New Learning; Non-conventional learning; Self-Directed Learning | |
| **10.0** | Development of Thinking and Ideas; Creativity; creative thinking; problem-solving | **Creative Aspects** |
| **16.1** | | **Practical Aspects** |
| 6.0 | Connecting Theory to Practice | |
| 8.1 | Process of Building | |
| 2.0 | Process of Breaking-In | |
| **36.3** | | **Motivational Aspects** |
| 13.4 | Motivating, challenging, Develops curiosity; interest; challenge; develops ambition | |
| 2.7 | Personal satisfaction | |
| 8.1 | Prizes and competition | |
| 9.4 | Fun | |
| 1.3 | Personal responsibility | |
| 3.4 | Development of Interest in Science | |

Table .4. Student Questionnaire: "What is the cost that the student 'pays' for participating in the competition? (N= 71)

| Average | Definitely Don't Agree | Don't Agree | Agree | Agree A Lot | Statement |
|---|---|---|---|---|---|
| 3.32 | 0 | 8 | 32 | 31 | 1. The student's participation burns up a lot of time. |
| 2.25 | 18 | 27 | 16 | 10 | 2. The students neglect their studies in other disciplines. |
| 1.70 | 37 | 24 | 4 | 6 | 3. Participating distracts the students from learning physics in school. |

Table **.** 5. “What were Negative Aspects About the Competition**?.**?” Categorization of Student Responses (N=67 comments of the 72 students).

| **Percentage of Responses** | **Response Sub-Categories** | **Reponse Categories** |
|---|---|---|
| 22.4 | | No Comment |
| | | |
| 19.5 | | The Safe |
| 9.0 | Irrelevant “Tricks” | |
| 1.5 | Multiple principles of physics involved | |
| 4.5 | Difficulty level too high; need to limit physics principles | |
| 1.5 | Ideas not original (copied from year to year) | |
| 3.0 | Safes were physically broken | |
| | | |
| 3.0 | Lack of standard grading criteria | Evaluation |
| | | |
| 24.0 | | Competition |
| 6.0 | Too much adult involvement | |
| 4.5 | Background levels of the participants not equal | |
| 9.0 | Not enough prizes; it’s disappointing when you don’t win | |
| 1.5 | Size of team too small | |
| 1.5 | Unfair practice: teams tell others how to unlock safes | |
| 1.5 | Too much of a competitive atmosphere | |
| | | |
| 13.4 | Took too much time; students neglect their studies because of time pressures | Time |
| | | |
| 1.5 | Cost too high | Financial Cost |
| | | |
| 14.9 | Organization problems; problems relating to staff, schedule, space | Organization and Management |
| 1.5 | | Miscellaneous Comments |

Table 6. Summary of Contributions and Costs of the Shalheveth Freier Physics Tournament. The table lists the contributions and costs, according to the students and the teachers. Percentages of student responses in the open-ended questions have been rounded-off to the closest percentage point.

| **Teachers** | **Students** | | |
|---|---|---|---|
| Open-Ended Questions and Interviews | Open-Ended Questions | Close-Ended Questions | |
| Increased student motivation, excitement and science learning<br><br>Improved relationship of teachers with students<br><br>Enhanced staff relations<br><br>Enhanced professional and personal satisfaction | Motivational Aspects (36%)<br>Social Aspects (19%)<br>Cognitive Aspects (19%)<br>Practical Aspects (16%)<br>Creative Skills (10%) | Design Experience<br>Creative Skills<br>Affective Benefits<br>Social Benefits | **Contributions** |
| Inadequate recognition of student work<br><br>Time issues<br><br>Lack of school support, encouragement and incentives for teachers<br><br>Lack of expert advice<br><br>Lack of equipment | Competition Aspects (24%)<br>No Comments (22%)<br>Technical Aspects (20%)<br>Organizational Aspects (15%)<br>Time (13%)<br>Evaluation (3%)<br>Financial Cost (2%)<br><br>Lack of School Support (lack of school-based time, equipment, financial assistance, mentoring, encouragement) | Time | **Costs** |

Figure 1. Number of Teams in the Shalheveth Freier Physics Design Tournament. The data show how many 5-person teams started and finished the competition, during the years 2001 to 2005.