Session 2332

# Fire-Fighting Robot Competitions and Learning Outcomes: A Quantitative Assessment

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Abstract

This paper presents a quantitative assessment of the Trinity College Fire-Fighting Home Robot Contest, the largest robot contest open to designers of any age, affiliation and experience [1,2]. Our assessment develops a profile of the participants, and it evaluates factors that motivate the participants, including interest in designing robots, interest in science and technology, career opportunities, and engagement of robotics as a hobby. The paper also evaluates participants' progress in eight key disciplines related to robot design, including electronics, teamwork, system design, and programming.

## I. Introduction

The Trinity College Fire-Fighting Home Robot Contest is the largest robotics competition in the world that is open to contestants of any age, affiliation, ability, and experience. The contest offers a design challenge that can be addressed at varying levels of technical sophistication, and it has attracted NASA scientists and professional engineers, college and high school students, and even fourth-graders. Fully operational robots have been built by single individuals and by teams as large as 15 persons. The event has been covered widely in the print media with articles *in Electronic Design, Popular Mechanics, Circuit Cellar INK, Byte,* the *London Times,* and the *New York Times*. Regional fire-fighting contests have been held in Calgary, Seattle, Fort Worth, and Philadelphia. In 2000 a regional contest will involve both secondary-school and university-level design teams in Israel.

Of the 87 robots entered in the 1999 Trinity fire-fighting contest, 73 robots, involving 237 team members, actually competed. In the last two contests some 35 college and university teams have competed in the contest's senior division, and 28 accepted the design challenge in 1999. Entrants included persons from Tufts, Yale, M.I.T., the U.S. Air Force Academy, Penn State University, Trinity, University of Texas, New Mexico Tech., Ohio State, Drexel, the U.S. Naval Academy, the Swiss Federal Institute of Technology, and Chiang Mai University in Thailand. Moreover, thirty-two robots were entered in the 1999 contest's junior (K-12) division. High-school participants came from Michigan, New Jersey, New York, Ontario and Pennsylvania, middle-school teams came from Georgia and New York. There were also five high-school teams with 24 students from Israel where the Ministry of Education authorized robotics as an optional matriculation subject [3]. While engaging university and high-school students from a wide geographical area, the contest has provided an ideal medium for introducing talented, under-represented female and minority Hartford-area high-school teams to the field of engineering. Through the United Technologies Trinity College Engineering Initiative (UTCEI) these students (UTCEI scholars) engage in research projects working with Trinity faculty and students during the school year and the summer. UTCEI robot teams have designed fire-fighting robots and participated in the contest for three years [4].

This paper presents a survey study that was conducted at the 1999 competition in Hartford in order to examine the nature of robotics as a medium for educating students and to evaluate achievement of outcomes. The survey data were collected by means of questionnaires and personal interviews and included characteristic data on the contestants, their activities, motivation levels, and attitudes. A number of common features that characterize specific groups of participants (working engineers, university students, and high-school students, for example) were discovered by the survey and are reported here.

## II. Contest Objective

The object is to develop a computer-controlled, autonomous machine that can navigate through a 8 ft. by 8 ft. maze, find a lit candle, and extinguish it in minimum time. The maze geometry, which is known by the contestants, includes four rooms and connecting hallways (Fig. 1). The walls of the maze are 13" high and are painted white, the hallways are 18" wide; and the floor is painted flat black. The robot must operate without human intervention of any kind.

The candle can be in any of the four rooms, and the position is not known by the robot. Before extinguishing the candle, the robot must navigate to within 12" of it and show that it has recognized the flame. Each robot makes three runs, which begin at a designated starting spot. The score is the sum of the fastest two run times. Reduction factors are applied for reliability, obstacle avoidance ability, ability to return to the starting location after extinguishing the flame, ability to trigger operation using a simulated smoke alarm, and non-dead-reckoning operation [2]. Full contest rules are found at the contest official site [1].

The robot contest was conceived as an incentive that would encourage learning and to help advance robotics technology, with these specific goals:

1. To proven an incentive for the robotics community to develop a practical robot for a real-world problem of fire security operation. As a result, the contest offers a fire-fighting task that requires speed, ability to navigate, ability to avoid obstacles, and ability to extinguish a flame.

2. To promote technology by giving an inducement for roboticists to try new techniques to solve a practical real-world problem. We believe in iterative improvement of robot designs, and the annual contest offers the opportunity for inventors to continually develop new technologies and robot capabilities.
3. To encourage students to get involved in Robotics. The next breakthroughs will not be made by adults, but by students who are still in college, or in K-12 classes. Building a robot offers a unique educational exercise that provides hands-on experience in physics, mechanics,

hardware, software, and teamwork. Students also learn how to overcome failure and how to plan and organize a long-term, multi-faceted project.

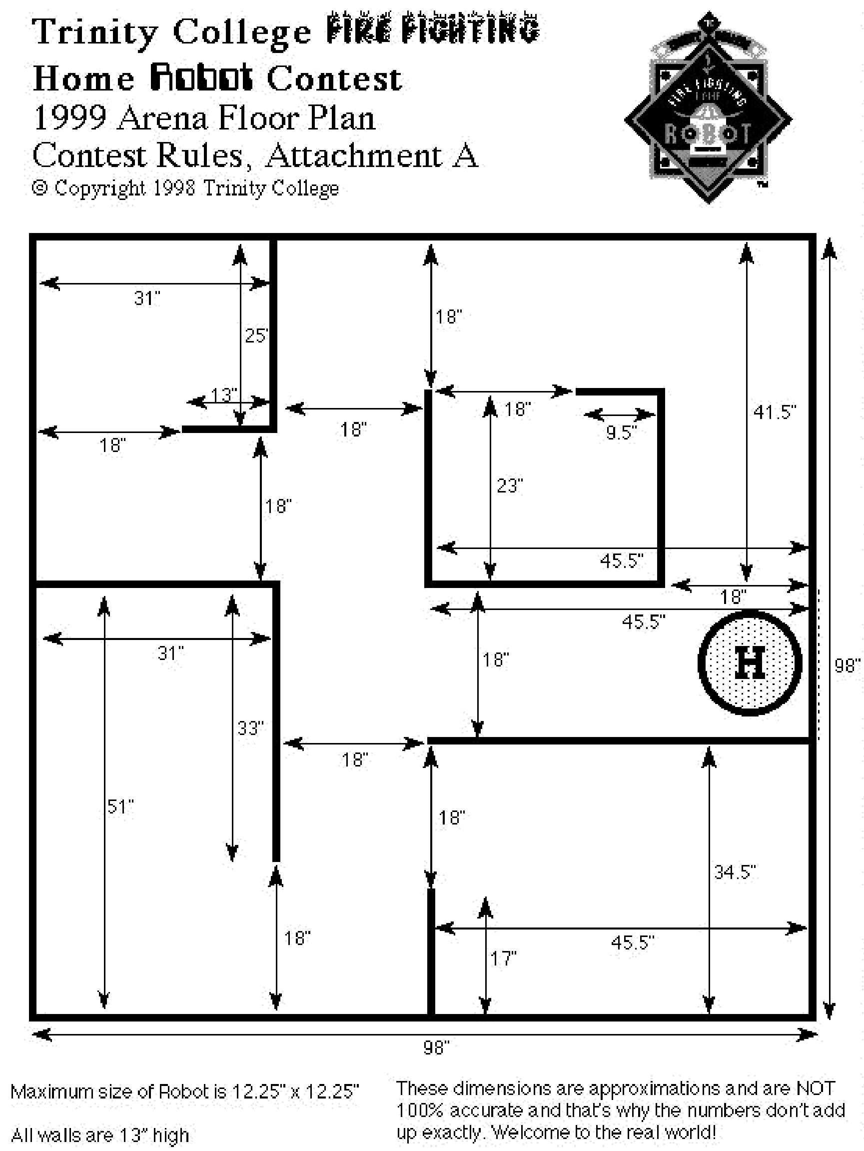


Fig. 1. Contest Maze

The development of an autonomous fire-fighting mobile robot is a challenging problem for competitors at all levels. This design problem is ideally suited to solution by an interdisciplinary team, an approach that is consistent with the Accreditation Board for Engineering and Technology's (ABET's) EC2000 criteria for undergraduate engineering education.

Students involved in fire-fighting robot design must invent a reliable mechanical system including wheels, gearing, and structural components; develop a computer-controlled motor drive system; choose sensors for wall following, candle detection, and surface feature detection; pick a microprocessor with sufficient analog and digital I/O ports, memory, and CPU speed to handle real-time data; and use available software tools to develop real-time codes that enable autonomous operation. Those who have participated fully in fire-fighting robot design will have accumulated knowledge in many of these areas: software design, mechanics, sensors, electronics, microcontoller interfacing, and motor control. In addition, this project could be expected to provide significant experience in interdisciplinary teamwork.

In the 6 years of the contest, we have seen tremendous improvements in the level of the competing Robots. The fastest times have dropped from 3 minutes in the first year to under 10 seconds in 1999. This improvement in the technology and its practical application and the participation of people of all ages from all over the world validate the contest and its goals.

## III. Contest Evaluation

On the day of the robot contest all participants were asked to fill out a survey form that included six sections. The first section related to general data (name, state/country, company/institution, team and position), and the second section requested information about past experience in robotics. Each respondent was asked to estimate his/her progress in a number of disciplines gained by working on the contest project. The list of disciplines included electronics, computers, programming, mechanics, control, systems design, robotics laboratory, and teamwork practice. The senior division participants were asked to specify their prior knowledge in these areas.

The third section of the questionnaire asked the respondents to specify their own activities in the following project-related subjects: drive mechanisms, control circuits, sensor system, steering planning, extinguishing device, and system software. In the fourth section, the contestants were asked about the forms of their participation in the robot contest program. They were asked to select relevant forms from the following list: part of a formal course, extracurricular activities, job related research, graduation project, or hobby.

The fifth section included the question: "To what extent are the factors mentioned below important for your participation in the robot contest?" The list of motivation factors was formulated in one-to-one correspondence with Wlodkowski’s six categories of learning motivation [5]. An additional factor allied to professional motivation was included in the senior division survey form. The list of motivation factors is presented below in Table 3.

In the last section of the questionnaire the participants were asked to estimate the contribution of the contest to development of their attitudes towards robotics and engineering. The list of attitudes included: interest to designing, building and programming robot systems, interest to learn science and technology subjects, and interest in entering an advanced level engineering program. The senior division form included also attitudes towards career opportunities and hobby subjects.

A personal interview form was addressed to people involved in the robot contest. With this form they were asked to present their opinions on robot contest involvement and to provide substantiating examples.

## IV. Survey Results

### A. General

Answers were obtained from 112 respondents (45 team-members in senior division, 61 in junior division and 6 instructors) out of the whole population of 237 participants registered for the contest. Four groups of the participants were examined in the survey: middle (junior high) school and high school students, university students (engineering majors) and engineers.

Distribution of the respondents according to the groups is as follows: University students 39.0%, Engineers 4.8%, High school students 46.7% and Middle school students 9.5%. Two main groups of the contestants were high school (grades 10-12) and engineering students. Most of the university students were at the bachelor's degree level.

### B. Progress in disciplines

The data on progress in disciplines due to the robot contest project, given by participants of the four groups, are summarized in Fig. 2. Eight patterns in the diagram correspond to the eight disciplines. Each pattern consists of four columns, indicating average levels of progress in a certain discipline given by participants of the four groups. The left column is for junior high school students, the next columns are for high school students, university students and engineers. The rating scale for progress in disciplines is as specified in Fig. 2: 0 No, 1 Limited, 2 Considerable, 3 Extensive.

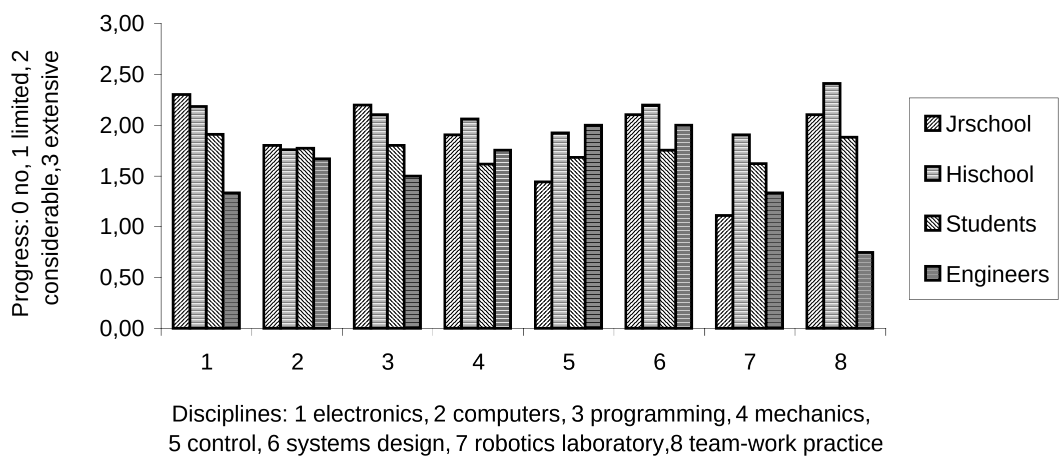


Fig. 2. Progress in disciplines

According to Fig. 2, all groups achieved progress in every discipline. This result indicates that robot contest designs introduced all groups to an integrated view of engineering science subjects. The levels of progress given by K-12 students for most of the disciplines are between "considerable" and "extensive". This fact indicates that robotics projects are within school students' powers and can provide them with broad technical backgrounds. The highest progress is reported in electronics, programming, systems design and team-work practice, subjects which are beyond conventional school curricula.

Participating university students assign fair (1.50) and higher grades to their progress in all eight disciplines. This shows the value of the fire-fighting robotics projects for integration of knowledge and gaining insight into hi-tech engineering.  Significant progress was mentioned even by the post-graduate engineers participated in the contest. They reported considerable and higher progress in control and systems design, and fair and higher grades to their progress in computers, programming and mechanics.

The progress grades given by the university students and the post-graduate engineers can be compared with the grades of background knowledge in the same disciplines. As follows from the diagram in Fig. 3, the students started work on the robot contest projects with limited or generally no prior knowledge in the disciplines except for knowledge in computers and programming. The results show that the projects provided students insight into all engineering disciplines that were surveyed.

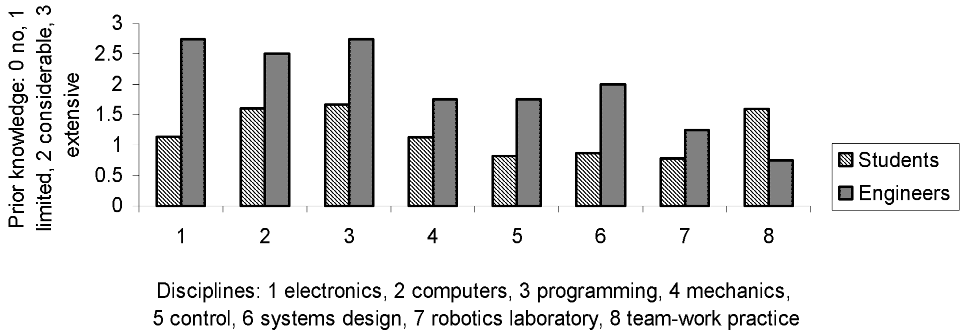


Fig. 3. Prior knowledge in disciplines

Post-graduate engineers assigned fair grades to the progress in electronics, computers and programming (see Fig. 2).  This may be the result of their thorough prior knowledge in the disciplines (grades higher than 2.5 in Fig. 3). The main progress was achieved in mechanics, control and systems design, areas in which these engineers had less prior expertise (grades 2.0 and less in Fig. 3).  As follows from Fig. 4 the post-graduate engineers had limited teamwork experience. Most of their robot projects were individual ones that did not include teamwork.  The projects of most of them were individual and did not include team-work practice.  Therefore, from the educational point of view, these engineers should be encouraged to work in teams.

C. Activities

Four diagrams presented in Fig. 4 below characterize involvement of the respondents in learning, applying, producing and designing activities in the subjects related to the robot contest project. Each diagram consists of six patterns corresponding to six subjects listed on the bottom of Fig. 4. The pattern includes four columns, indicating relative involvement in a specific subject and a certain activity of contestants from the four groups: junior high school students, high  school students, university students and engineers. The groups' legends are shown to the right of the diagrams.

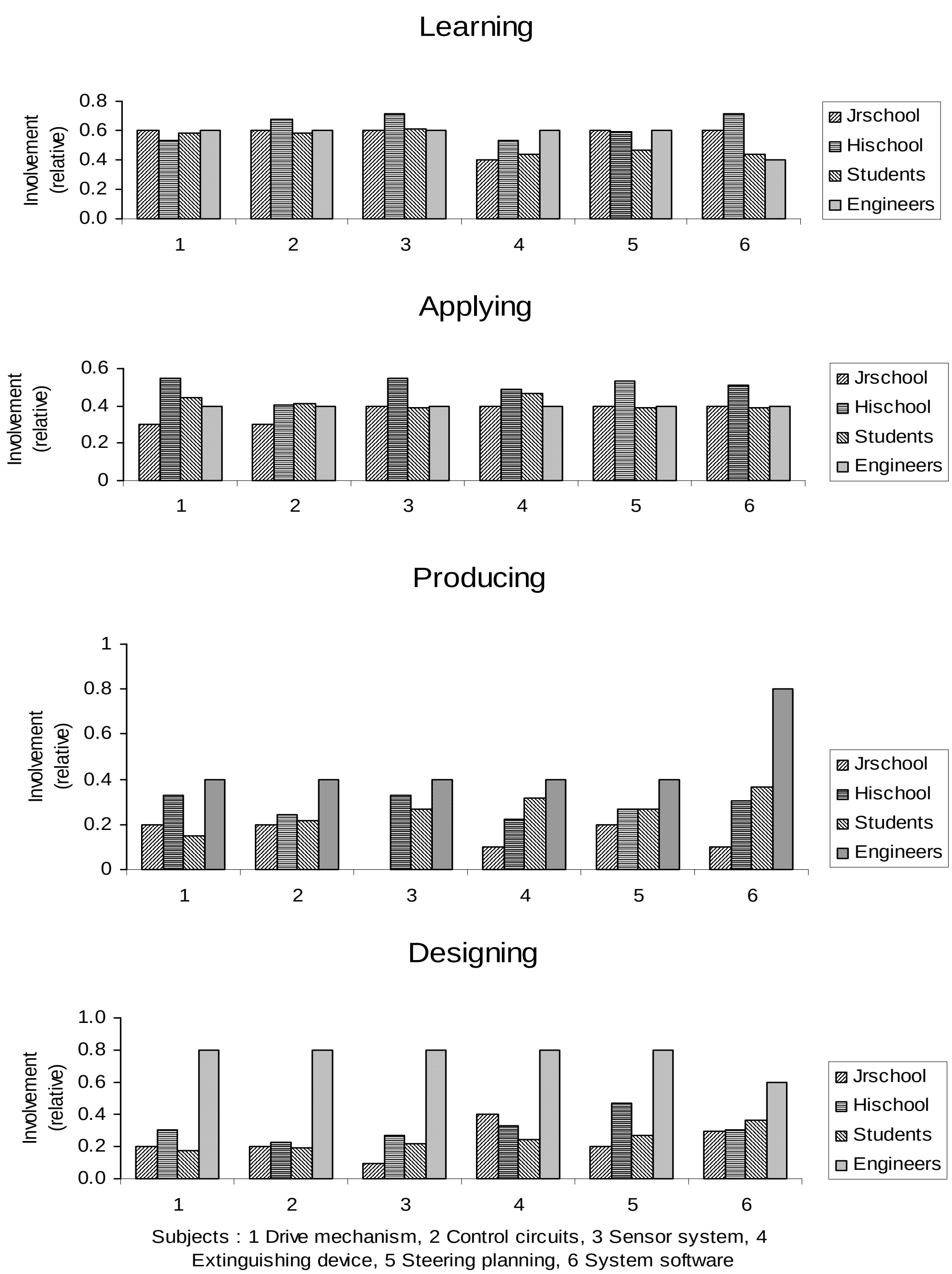


Fig. 4. Involvement in different activities and subjects

The first diagram indicates involvement of about 60% of the respondents from all groups in learning every subject. In fact, the majority of the contestants learned four or more subjects. Lower involvement of students and engineers in learning system software probably is caused by their prior knowledge in this subject.

The second diagram shows that more than 40% of the contestants dealt with applying drive mechanism, control circuits and each of the other subjects in their project. Relative involvement of high school students in applying the subjects (about 50%) is above all other groups.

As follows from the third and forth diagrams, engineers were involved in producing and designing activities more than other groups. However each university and high school student participated in producing and designing activities related on average to 2-3 subjects listed in the diagram.

D. Forms of participation in the contest

Table 1 presents relative involvement of the four groups of respondents (columns 2-5) in various forms of participation in the contest (listed in the first column). As follows from the table, the groups had different reasons in choosing to participate in the contest. Participation of junior high-school students in robotics projects was primarily in the form of extracurricular, hobby activities, or private course.

Table 1. Share of different forms of participation in the robot contest (%)

| | Junior school | High school | Students | Engineers |
|---|---|---|---|---|
| Part of the course | 25 | 15 | 51 | 20 |
| Extracurricular activities | 88 | 72 | 63 | 60 |
| Job related research | 0 | 4 | 2 | 20 |
| Graduation project | 0 | 33 | 7 | 0 |
| Hobby | 50 | 28 | 41 | 100 |

One third of the senior high-school students participated in the contest as part of their graduation projects. These data show that robotics projects have achieved curricular standing in a number of schools. More than a half of the university students participate in the contest as part of their courses. This offers evidence that the fire-fighting robot contest has been incorporated in the undergraduate engineering classroom in a number of universities. All responding post-graduate engineers considered participation in the contest as a hobby.

E. Motivation

The survey data on personal motivation for participation in the contest are summarized in Table 2. The motivation factors are listed in the first column of the Table. The second, third, fourth and fifth columns present data about specific groups of respondents. The number in each cell shows the percentage of respondents who consider the motivation factor important or very important for their participation in the contest.

The data presented in Table 2 indicate that high level motivation of respondents for participation in the contest is influenced by a combination of motivation factors. For junior and senior school higher grades were assigned to the contest's subject, method and framework, and to enjoyment of robotics competition. The university students had other priorities; they assigned the higher grades to the opportunity to apply their ideas and to the practical value of knowledge acquired in the contest. The engineers were motivated mostly by the opportunity to apply their ideas (like university students), enjoyment of robot gaming (like school students) and by the desire to win the contest reward. "Demonstration of professional skills" was considered by the groups of university students and engineers as a motivation factor of significant but not the highest importance.

Table 2. Motivation for participation in the robot contest program

| Motivation factors | Jr. school | Hi. school | Students | Engineers |
|---|---|---|---|---|
| 1. A positive attitude towards the subject, the method and the framework suggested by the contest | 100 | 96 | 78 | 80 |
| 2. Awareness of the practical need of knowledge and experience acquired through participation in the contest | 80 | 87 | 93 | 80 |
| 3. Prizes, travel grants and other stimulation of your participation in the contest | 50 | 41 | 27 | 20 |
| 4. Taking pleasure in robot gaming | 100 | 93 | 85 | 100 |
| 5. Ambition to cope with the contest challenges and win a reward | 90 | 74 | 71 | 100 |
| 6. Opportunity to apply your ideas, and reinforce practical and learning skills | 80 | 91 | 95 | 100 |
| 7. Demonstration of professional skills | | | 76 | 80 |

Each factor is important to a certain group of the respondents. Although all the groups assigned the lower average grades to the extrinsic stimulation factor, it was important for a significant number of the respondents--especially school students (40-50 %).

F. Attitudes

Respondents' opinions about the contribution of the contest to developing interest in robotics and engineering are listed in Table 3.

Five examined factors are listed in the first column of the table. Each cell in the second, third, fourth and fifth columns present average grade given by a specific group of contestants to the contribution of the contest for the particular factor. The rating scale for contribution of the contest is: -1 Negative, 0 No, 1 Positive, 2 Strong positive.

Table 3. Contribution of the contest for personal activities

| Attitudes | Junior school | High school | Students | Engineers |
|---|---|---|---|---|
| Interest to designing and building robots | 1.4 | 1.7 | 1.4 | 2.0 |
| Interest to learn science and technology subjects | 1.3 | 1.6 | 1.5 | 1.2 |
| Interest to enter an advanced engineering program | 1.1 | 1.3 | 1.1 | 1.0 |
| Career opportunities | | | 1.1 | 1.0 |
| Hobby subject | | | 1.1 | 2.0 |

Table 3 testifies that the contest exerted significant influence upon the participants. For all the factors and all groups the average grades are in the range of "positive" and "strong positive" contribution. In particular, the contest promoted interest of the majority of the contestants to design, build and program robot systems, to learn science and technology, and to pursue advanced engineering studies. The contest helped university students and engineers to find career opportunities and to develop a favorite hobby.

G. Personal interviews

The purpose of personal interviews was to survey individual views of the educational value of the robot contest. Quotations from several interviews are given below.

*James Mc Sherry (Carver High School of Engineering & Science, Pennsylvania):* "I have sponsored students from our school to The Fire Fighting Robot Contest for four years. All the students who participate have shown increased interest in digital electronics, programming, and engineering. Students spend hours of development time, or their lunch or after school, improving robot design and writing or correcting programs. The enthusiasm they show is obvious."

*Kundan Nepal (Trinity College, Connecticut, student from Nepal):* "The contest I feel was an important contributor for my increased interest in Robotics. When I came to Trinity, I was sure I wanted to be an engineer, but was not sure as to which field of Engineering I should choose. My involvement in the Trinity College robot team help me make up my mind – electrical engineering. Making a robot for the contest with a couple of others really exposed me to the challenges I was to face as an engineer. I feel that the contest really gave me a feel for the expectations of the real Engineering world and prepared me to face any challenge without giving up."

*Douglas S. Green (Saint Michael's College, Vermont, Associate Professor of Computer Science):* "I have found the robot contest to have high educational value. Saint Michael's is a small liberal arts college. We do not generally offer "specialized" courses like robotics or real-time programming in our computer science curriculum. This contest gives my students their first understanding that programs that need to interact with the real world require another level of thought and design to work effectively. The exposure to electronics, real time programming and robotics techniques is a real benefit for my students. Another benefit is that they learn that project work can be fun, and that not all work has to be part of a course or a part-time job. Finally, they gain real experience with "crunch-time" programming before the contest."

## V. Conclusion

This paper has introduced the Trinity College Fire-Fighting Home Robot Contest and it has reported on a survey of 112 participants in the 1999 contest. The survey indicates that the contest has had a positive educational impact on K-12 students, undergraduate engineering students, and on post-graduate engineers. Each group gained expertise and realized benefits of improved technical abilities.

The great majority of the high school and university students started work on the robot contest projects with generally no or limited prior knowledge in engineering and made considerable progress in electronics, programming, systems design and other engineering subjects. The learning process integrated applying, producing and designing activities in various subjects.

High level motivation of respondents for participation in the contest is indicated. Motivation of each contestant is influenced by a certain combination of motivation factors, while every factor is important to some individuals.

A positive change of students’ attitude towards robotics and engineering due to participating in the contest was indicated, as expressed in their interest to designing and building robots, to studying science and technology subjects and majoring in engineering.

Robotics courses based on the fire-fighting robot contest projects have been successfully incorporated in the classroom in a number of universities and high schools. We believe that instructional materials as well as adequate assessment and accreditation of the robotics curricula will provide wide future expansion of this form of engineering education.

## VI. References


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