**Robotics Olympiads: A New Means to Integrate Theory and Practice in Robotics**

Igor M. Verner, Technion--Israel Institute of Technology
David J. Ahlgren, Trinity College
David P. Miller, University of Oklahoma / KISS Institute

**Abstract**

This paper proposes organization of theoretical robotics competitions that, in conjunction with practical robot contests, provide students with a framework for effective learning and development of engineering aptitude. Experiences with integrating theoretical tests in the Trinity College Fire-Fighting Home Robot Contest, National Botball Tournament, and International Robot Olympiad are presented.

**Introduction**

Robot competitions are widely recognized as effective motivational and organizational frameworks for robotics research and project-based engineering education. Many educational institutions develop programs in which student teams perform robot design projects through curricula and extracurricular activities and participate in local, national and international robot contests. As motivators, guides, communicators, and evaluators of contest-oriented projects [1], robot contests provide students with experience of social interaction. Such experience is considered in education as an essential component of student cognitive development [2].

With rapidly increasing level of sophistication and reliability of robots required by the contests, robotics educators are developing new approaches to design, implementation, and evaluation of effective robotics curricula and dissemination of best practices of robotics education. This paper considers one of the aspects of robotics education; namely, understanding science and engineering concepts acquired through learning-by-doing activities in the robot project. We emphasize the need for student understanding of knowledge acquired through a robot project and propose to facilitate it by introducing theoretical tests (Robotics Olympiads) as integral parts of robot contests. We present our experience of theoretical tests at the Trinity College Fire-Fighting Home Robot Contests [3], Botball Tournaments [4], and International Robot Olympiads [5].

**Teaching for Understanding and Aptitude Development**

Aptitude can be defined as a capacity or potential for achievement in a given area based on the ability to understand phenomena and principles both formally and through experience [6]. The three components of the aptitude are knowledge, ability, and motivation.

Development of aptitude and understanding is not an automatic result of any learning process. From the experience of educational studies in mathematics and science education, students in the course “can acquire knowledge and routine skills without understanding their basis” [7]. Summarizing results of a large-scale project focused on teaching for understanding [8, 9], Unger pointed that in order to facilitate students’ understanding, instruction should answer the following requirements:

- Design a curriculum around topics connected to students' interests and experience, and that are central to the discipline.
- Clearly articulate and share with students goals of understanding.
- Engage students in performances that cause students to do a great deal of thinking when using, applying, and enriching their knowledge and skills through challenging work.
- Practice assessment that actively involves students in reflection on their learning.

Olympiads in science, mathematics, and other subjects are popular events that offer students opportunities to demonstrate knowledge, abilities, and motivation through competitive examinations. Examples include the International Olympiads in Mathematics (IMO), Physics (IPhO), Chemistry (IChO), Biology (IBO) and Informatics (IOI) [10]. Several of these offer both theoretical and experimental components. These Olympiads bring together the best high-school competitors from the around the world and bear considerable weight when inspiring in-depth understanding and aptitude development.

In robotics education, many of the characteristics that we would like the students to acquire in the robot projects and demonstrate at the robot contests are implied in the concept of engineering aptitude. The engineering aptitude characterizes readiness of the individual to master engineering and technology or to pursue an engineering/technical career [11]. Aptitude tests include engineering and technological problems, which require understanding theoretical concept and ability to use them in practice [12].

For example, the questions posed in the NEAS tests for secondary school students who did not study technology/engineering subjects cover the following topics:

- Mathematical reasoning. Students solve practical problems and use mathematical methods studied in school algebra, geometry, trigonometry, number theory, and probability.
- Science reasoning. These tests assess students' ability to understand the purpose of experiments, analyze new situations, examine hypotheses and draw findings.
- Practical understanding. Students demonstrate their ability to understand the interaction of forces in mechanical devices, to use the principles of object movement in physical systems, to visualize and mentally manipulate three-dimensional objects.

The wide scope of subjects, practical and technical skills that students can gain through robotics education make it an ideal environment for development of their engineering aptitude. In order to inspire this development we propose to organize theoretical robotics competitions (Robotics Olympiads) in which students will demonstrate in-depth understanding of robotics concepts. The conjunction of practical robot contests and theoretical tests provides a framework for comprehensive assessment and reflection needed for effective learning and aptitude development.

## The Olympiads

In this section we will describe robotics Olympiad tests that were conducted at the Trinity College Fire-Fighting Home Robot Contest in 2003-2005, at the National Conference for Educational Robotics in 2004 and 2005, and at the International Robot Olympiad held in Korea in 2004 and 2005. We will point out commonalities and differences among these tests and the related contests, present examples of test questions, and evaluate student experiences based on test results and user surveys.

The first robotics Olympiad was held in 2003 as part of the Trinity College Fire-Fighting Home Robot Contest (TCFFHRC) [13, 14]. Since 2004, the Botball program has adopted the TCFFHRC Olympiad exams and has administered them annually to well over 150 participants, including junior high students, high school students, and professional engineers as part of the National Conference on Educational Robotics [15]. The goals of the TCFFHRC Olympiad exam include the following: (1) to measure student knowledge beyond that indicated by robot performance; (2) to promote academic achievement in robotics subjects; (3) to provide (in some cases) a bonus to augment robot performance scores; (4) to reward the most knowledgeable individuals and teams; and (5) to provide an incentive for future Olympiad participation.

The TCFFHRC Olympiad exam covers four fields that are central to robot design: mechanics, electronics, software, and sensors. Linked knowledge in these areas is essential to the completion of a successful fire-fighting or Botball robot. Knowledge in mechanics enables students to develop drive systems and mechanisms, and to develop a sufficient understanding of robot kinematics. Some expertise in electronics allows students to develop sensor circuitry, understand signals and noise, apply semiconductor sensors, and develop necessary signal conditioning circuitry. Knowledge of software programming is essential to developing logical algorithms for sensing, navigation, and control. Finally, we focus on sensors, which provide information about the robot's surroundings, enabling navigation and control algorithms to make correct decisions for autonomous behavior. We note that robotics is an ideal interdisciplinary medium for teaching for understanding many important engineering concepts related to hardware-to-software interfaces, programmed control of motor drive systems, and issues of energy storage and conservation.

**Implementation at Trinity**

Established in 1994, the Trinity College Fire-Fighting Home Robot contest is an international competition that is open to persons of all ages, affiliations, and levels of skill. In the TCFFHRC teams design autonomous robots that can find and extinguish a fire as quickly as possible in a model house [10]. In 2005, 120 robots from five continents competed at Trinity College in April. Teams from more than ninety colleges and universities have competed, and regional events that use the TCFFHRC rules have been held in such locations as Beijing, Buenos Aires, Calgary, Los Angeles, Philadelphia, Tel Aviv, Seattle, Shanghai, and Singapore. The contest has five divisions, Junior, High School, Senior, Expert, and Walking. The reader will find the contest rules at the official website [3].

In 2003 and 2004 the Olympiad exam was administered with the following caveats: (1) the exam is open to individuals and teams who have designed a robot and who have registered for the competition in the Junior Division or the High School Division; (2) for each Division there are two exam categories, one for individuals and one for teams; (3) all Olympiad participants will take the same exam; (4) the tests will be 50 minutes long; and (4) each division will have its own rewards and certificates; and (5) if a robot fails to extinguish the candle during the contest qualification trials, then its contest score will be enhanced with bonus points earned in the Olympiad. In 2005 the Olympiad was opened up to all contest registrants, and all groups took the same exam. Four teams and two individuals from universities took the test.

The 2003 participation at the TCFFHRC was representative of the three years. Students in both individuals and teams divisions took the same exam. Participants in this first TCFFHRC Olympiad included two individual junior students (grades 6 and 8), six individual high-school students, and ten high-school teams with a total of 45 team members

**Implementation at the NCER/Botball Competition**

The National Conference on Educational Robotics (NCER) is held annually. This four-day multi-track conference is formatted like most other mid-sized (about 400 registered attendee) conferences, however about 80% of the registrants and over half the presenters are below the age of 19. The rest of the speakers (with the exception of the plenary speakers) are middle and high school educators or Botball team mentors. The conference also contains several special events including the World Botball Championships, the Beyond Botball Tournament, the robot trivia contest, and an adaptation of the TCFFHRC Olympiad. (see www.botball.org for more information).

The NCER conference has events scheduled from 8 am until 9 pm each day. The Olympiad, which is open to all registered participants at NCER, is scheduled just before dinner on the second day of the conference. When given the option of having a longer dinner break or taking a written exam (the Olympiad), more than 100 people each year took the exam.

The breakdown of the population taking the Olympiad was very similar for both years. 10% of the participants were adults. A couple of these adults were high school teachers while the rest were Botball mentors who were professional engineers -- The remaining 90% of the Olympiad participants was evenly split between middle school and high school students. About one quarter of the participants chose to enter the Olympiad as teams (interestingly, most of the adults entered as teams; there were slightly more middle school teams than high school teams; there were two mixed age teams each year). Overall, there were about ten teams and seventy individual entries each year. The average team size was three people.

In 2004 the test used at NCER was based off the 2003 TCFFHRC Olympiad with programming questions added (14 multiple choice questions in total). The test questions were edited slightly based on clarification feedback from earlier uses of the test. In 2005, the test was a subset (10 short answer questions) of the 2004 TCFFHRC Olympiad. Again, the questions were edited slightly for clarity, based on feedback.

**Olympiad Exam Design and Content**

Here we describe an exam given to TCFFHRC contestants in 2004 and, in edited form, to Botball students in 2005. The exam consisted of thirteen questions covering four subject areas mentioned above. Two of the authors contributed questions to the exam, and the lead author was the exam editor. The authors formulated some of the questions themselves, while others were inspired by questions found in mechatronics books and aptitude tests. We adopted questions across a range of topics and levels of difficulty. Each question presented a real problem that might arise during the robot project, and each required a solution based on theoretical background and practical experience.

To indicate our approach to question development and student responses, we describe below four of the eleven questions on the 2004 Olympiad exam. Unlike the 2003 exam, some of the 2004 exam was not multiple-choice.

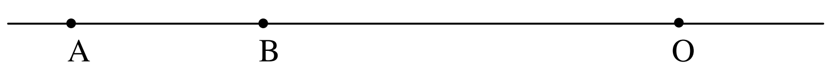
1. The first sample question required a simple calculation based on understanding the principle of stepper motor operation and the angular velocity concept. Students who had been involved in developing movement algorithms for their fire-fighting robots would likely be prepared to answer this question.

Q1: If a stepper motor has a step angle 7.5°, what is the digital input rate required to produce a rotation of 10 rev/sec?

Solution: The motor has 360°/7.5° = 48 steps/rev. Rotation of 10 rev/s requires 480 steps/sec.

2. The second sample question examined understanding the principles of light sensor operation and, from physics, how light intensity from a point source falls off as a function of distance. This behavior of light is important because most fire-fighting robots depend on light sensors to detect a flame, and many use reflectance sensors to determine distance to arena walls and other obstacles.

Q2: The light intensity from the source O measured in points A and B equals
$I_A = 4\ W/m^2$, $I_B = 9\ W/m^2$. The distance $|AB| = 0.4$ m .




The distance of point B from the light source O equals

$$|BO| = \_\_\_\_\_\_\_\_\_\_$$

Solution: Assume that the source at point O has intensity equal to $I_s$. Inverse square law behavior gives $I_s/|AO|^2 = 4\ W/m^2$ and $I_s/|BO|^2 = 9\ W/m^2$. Substituting $|BO| = |AO| + 0.4m$ and taking the ratio one obtains $4/9 = |BO|^2/(|BO| + 0.4m)^2$. Rearranging, one gets a quadratic equation

$$5|BO|^2 - 3.2\,|BO| - 0.64 = 0$$

that has two solutions, $|BO| = 0.8$m and $|BO| = -0.16$m, the first one feasible.

3. The third sample question relates to robot behavior analysis and examines understanding principles of sensor-based navigation. The idea to ask a question on this subject was proposed by Joseph L. Jones. This question poses three behaviors for the robot (Escape, Target, and

Forward) and so encourages students to think at the behavioral level when solving the fire-fighting contest's task. The problem also applies a flame sensor with a limited angle of sensitivity.

Q3. A task for the mobile robot presented in Figure (A) is to find a source of light (a lit candle) in a rectangular room and reach it. The robot control system employs three simple behaviors called Escape, Target and Forward.

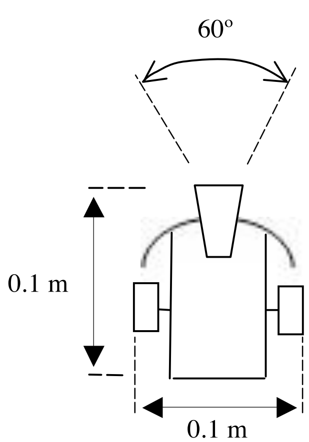
- The Escape behavior is initiated after the robot has collided with a wall. Escape causes the robot to draw back 0.1 m from the wall and turn left in a direction parallel to it.
- The Target behavior is initiated when the light sensor with a viewing angle of 60°, placed on the robot's front, detects light. When light is detected, the robot drives to its source using sensor feedback. It stops after reaching the light source.
- The Forward behavior represents driving straight forward without any conditions.

The motion control system handles the following priorities:

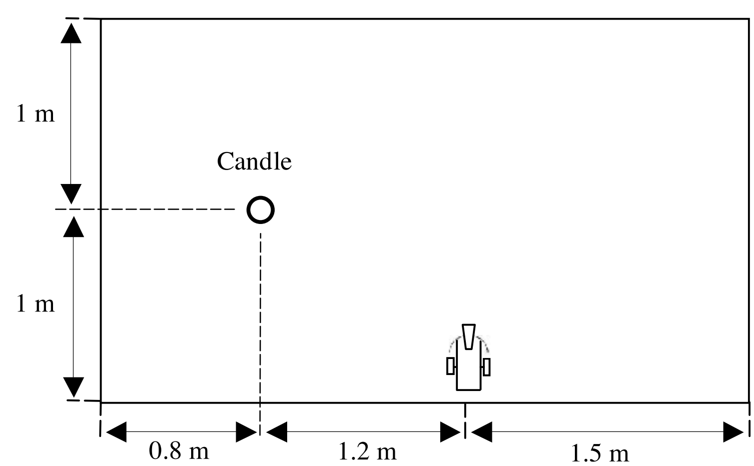
- Escape has the highest priority. The robot follows it when its condition is met (collision).
- Target has the second priority. The robot selects this behavior under its condition (light detection).
- Forward has the lowest priority. The robot follows it when Escape and Target conditions are absent.

Figure B shows the initial robot position in the room. Draw in the figure the trajectory of robot motion.

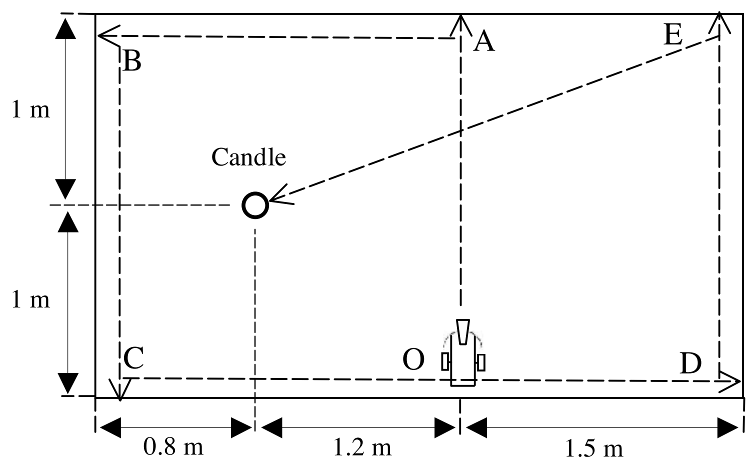
(A)




(B)




Solution: By applying rules of trigonometry, the student determines that the robot can't see the candle given the initial position (point O) and orientation. The robot moves upward until it collides with the top wall (point A below). Trigonometry calculation indicates that the robot cannot see the candle from any point on this first segment. When the robot hits the top wall near point A, it enters Escape mode, backing up 0.1 m from the wall and turning left. From that position (and from any point on A-B), it cannot see the candle, so it moves in Forward mode until it hits the left wall (point B) and enters Escape mode again (moving back 0.1 m and turning left). In a similar way the robot proceeds to points C, D, and E. At point E, the candle is within the sensitivity cone of the sensor, so the robot enters Target mode and drives to the candle.




4. The fourth sample question integrates three main concepts from the field of energy: storage, conversion, and electromechanical efficiency. The question requires students to understand the concept of battery capacity and to equate stored potential energy in the battery to gain in potential energy as the robot moves to its final position. The question also requires students to estimate sin(15°).

Q4. A robot that weighs 2.2 kg is equipped with a 9.6 Volt battery with a rated storage capacity of 100 milliampere-hours. The robot uses two d.c. drive motors. The overall efficiency of the robot, including friction and electrical heating losses, is 43%. Starting with a fully charged battery, the robot climbs a 15-degree incline at a constant velocity until the battery runs out. Approximately how far will the robot travel along the incline?
(a) 73 m (b) 127 m (c) 191 m (d) 265 m (e) None of the above (a) – (d)

Solution: The energy stored in the battery is (0.1 Amp-hr) · (3600 sec/hr) · 9.6 V = 3456 J. Because of inefficiencies, E = 0.43 x 3456 J = 1486 J is available for increasing the robot's potential energy. One can equate this available energy to potential energy through the following equation:

Gain in gravitational potential energy = Available electrical energy, or $m \cdot g \cdot h = E$,

where m = mass of robot, g = acceleration due to gravity, and h is the gain in height in meters. This gives the equality, (2.2 kg) · (9.8 m/sec$^2$) · h = 1486 J, giving h = 68.9 m. For an incline of length L, we have sin(15°) = h/L. It is possible to estimate sin(15°) knowing that sin(x) ≅ x for small x measured in radians. Here $x = 15 \cdot \pi/180 = 0.26$ so an estimate of L is $L = 68.9\ m/0.26 = 265m$.

**Exam Responses--TCFFHRC**

We tabulate below the fraction of correct responses for each of the four sample questions and for each of the competition categories (Table I).

Table I. Fraction of Correct Responses by Question and Category (2003)

| Category | Q1 | Q2 | Q3 | Q4 |
|---|---|---|---|---|
| Individual Junior (N=2) | 1 | 0.5 | 0.5 | 0 |
| Individual HS (N=6) | 0.5 | 0.83 | 0 | 0.17 |
| Team HS (N=10) | 0.9 | 0.6 | 0.3 | 0.2 |
| Overall | 0.78 | 0.67 | 0.22 | 0.19 |

The results in Table I suggest that these Olympiad questions presented a challenge for all participants. It is evident that questions Q1 and Q2 presented less of a challenge than Q3 and Q4, which involved integration of knowledge from different fields. It is likely that in approaching Q1, even students without experience with stepper motors could work out a solution by positing a theory about how steppers work. On the other hand, Q2 presumes that students know that light intensity falls off versus distance and that they can construct an equation to be solved algebraically. The exam papers showed that among those who answered Q2 incorrectly, 25% wrote something that suggested inverse square law behavior. These persons were not able to express the idea with a correct formula.

Q3 is an involved problem that requires careful reading and understanding and application of three robot behaviors. Q3 presents the exam takers with a new approach to robot motions, so the problem tests students' abilities to read an exam question and to gain understanding of new concepts through the question itself. The exam papers showed that five teams that had incorrect answers to Q3 succeed in understanding the behaviors but failed correctly to apply what was given about the sensor's acceptance angle.

Q4 requires integration of knowledge from physics and mathematics and its solution requires application of energy conservation principles (physics of gravity, efficiency, energy conversion). Q4 required the highest level of integration of knowledge, and it received a generally weak response. We note that the data for Q3 and Q4 are consistent with random answer choice.

It is also interesting to compare the overall scores across the competition categories. Table II presents the minimum, median, and maximum scores for the categories. Although it is evident that teams performed better on the exam than individuals, the improvement was not marked. In fact, the two junior students performed at nearly the same level as the high school individuals and teams, displaying that interest and knowledge in robotics can begin at an early age among highly motivated youngsters.

Table II. Scores by Category (N = 13 Questions) (2003)

| Category | Min. | Median | Max. |
|---|---|---|---|
| Individual Junior (N=2) | 6 | 7 | 8 |
| Individual HS (N=6) | 3 | 6 | 10 |
| Team HS (N=10) | 3 | 7.5 | 9 |

The TCFFHRC Olympiad was successful in engaging junior and high school students in a significant competitive event outside the regular robot competition. Through the Olympiad, students were given the opportunity to demonstrate knowledge of theoretical aspects of robotics, complementing the overall skills (both theoretical and practical) that promote success in the robot competition: design skills, hands-on skills, and teamwork, for example.

**Exam results—NCER**

The Olympiad results from the NCERs are interesting in several respects. Teams from a particular age group scored on average slightly above the average of the individual scores for that age group. However, with the exception of the adults in 2004, no other group obtained the high score for their age group. In 2004, the high scoring adult group (a group of senior engineers from a major defense contractor) tied the score of the high scoring individual high school student.

The highest scoring middle school student was always lower than the highest scoring high school student. However the lowest scoring middle school student was always higher than the lowest scoring high school student. This appeared to be due to the lower scoring high school students answering questions whether or not they had a clue to the answer – and getting a penalty for a wrong answer (in 2004). Middle school students appeared to be more content with leaving a question blank, rather than making blind guesses.

Results for the 2004 NCER test are shown in Table III. Note that this is the same test used in Table II, but with the addition of two programming questions covering variable scoping and arrays. The average team size for the 2004 NCER Olympiad was three people, there were 72 individuals taking the test and approximately 27 people as 9 teams taking the test. Note that there was not necessarily much correlation between the makeup of the Botball competition teams and the Olympiad teams.

Table III. Scores by Category (N = 15 Questions) (NCER 2004)

| Category | Min. | Median | Max. |
|---|---|---|---|
| Individual Junior (N=30) | 0 | 4 | 8 |
| Team Junior (N=4) | 3 | 4 | 7 |
| Individual HS (N=36) | 1 | 6 | 10 |
| Team HS (N=3) | 7 | 7 | 10 |
| Individual Adult (N=6) | 2 | 6 | 9 |
| Team Adult (N=2) | 8 | 9 | 10 |

Questions such as the example question Q4 above are normally not covered in public schools until high school physics (a class that is usually taken during the junior or senior year, if it is taken at all). However, a small but significant number of middle school students correctly answered questions such as Q4 and other questions dealing with digital circuits that are normally not covered anywhere in the public school curriculum.
It is not clear how students were able to correctly answer these questions (especially on the 2005 test where they had to write out explicit answers). We plan to add supplemental survey questions to each Olympiad question for the 2006 Olympiad. These survey questions will ask if this material was covered in school (and in what class), through their robotics activities or learned on their own.

**International Robot Olympiad in Korea**

The 2004 and 2005 International Robot Olympiads (IRO) were held in Korea [17]. The IRO competitions are part of the Federation of International Robot Soccer Association (FIRA) program chaired by Prof. Jong Hwan Kim of the Korean Advanced Institute of Science and Technology (KAIST). The Olympiad offers a series of robotic assignments for different competition categories addressed to three different age groups (under 12, 13-18, and over 19). Examples of contests in regular categories are “Robot Line Tracing” for juniors under 12 years old, “Stair Climbing Robot” for ages 13-18, and “RoboSoccer” for adults. The Creativity Category implements a different model of robot competitions with focus on the theme embodiment and performance.

Sixteen teams of school pupils competed in the Creative Category of the IRO 2004 in two age groups: under 12, and in between 13-18. The teams consisted of up to three pupils. The competition in this category lasted four days and consisted of the four contests described below.

*Robot concept design*
In this contest the teams were given five hours to develop a concept of a robot related to an assigned theme and to illustrate it on a poster. The design theme was announced to teams at the beginning of the contest. For example, the design theme for the 13-18 ages group in 2004 was "A flower robot" – a robot that cultivates and sells flowers. When assessing the poster the contest judges paid attention to the following aspects: theme embodiment, systematic observation of robot functions, design solutions quality, clear presentation, and aesthetic appearance.

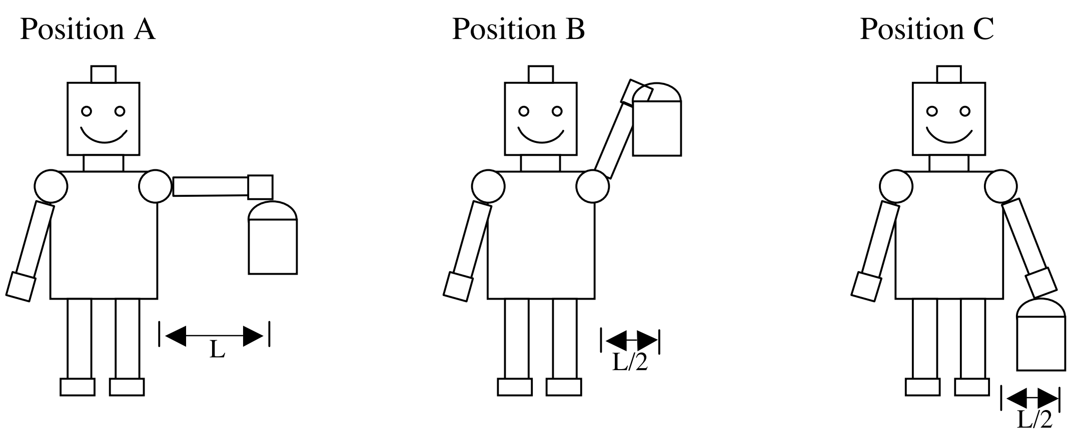
*Robot construction and operation*
The themes of this contest were announced on the IRO website three months before the competition. The teams used these three months to develop their projects. But at the competition, they were assigned to build robots from scratch and demonstrate its operation to contest judges. They had six hours to perform the assignment. Evaluation of the projects focused on the following aspects: theme embodiment, design concept, technical implementation, operation quality, and understanding principles of robot operation.

*Oral presentation*
The teams were given 10 minutes each for oral presentation of their projects. They presented robot systems, described design problems and explained their solutions. When evaluating the presentations the judges looked at understanding robotics concepts, level of problems, quality and originality of solutions.

*Written test*
The 2004 and 2005 theoretical tests were composed by one of the authors (Verner) and included in the Olympiad program as an unofficial event. Each of the tests consisted of ten multiple-choice questions which covered the areas of mechanics, electronics, programming, and sensors. Some of the questions were originally formulated; other questions explored ideas taken from mechatronics books and aptitude tests. Each question presented a real problem, which could arise during the robot project and required a solution based on theoretical background and practical experience in robotics. The following sample question tested basic level understanding of the torque concept.

<u>Question</u>. The torque value of the robot arm

(1) in position A is bigger than in positions B and C
(2) in position B ii smaller than in positions A and C
(3) in position C is bigger than in positions A and B
(4) is the same in positions A, B, C.
(5) is the same in positions A, C




98 pupils from the Creativity Category and regular categories took the forty-minute test in 2004. Their ages varied from 9 to 18. Dispersion of the pupils' achievements was between 0 to 7 correct answers (from 10 questions). As found, test achievements of some elder pupils were not higher than their younger companions.

## Conclusion

We have described theoretical robotics competitions (Olympiads) that we have coordinated with three international robotics competitions. The Olympiads have provided students a framework for learning and development of engineering aptitude. Our motivation is the belief that developing student understanding of engineering concepts and ability to apply and integrate knowledge is an important goal in educational robotics, a goal that will guide student learning and Olympiad development.

Challenging questions such as Q3 and Q4 presented in the paper can provide guidance to improving learning and instruction in robot projects. The first lesson is provided by Q3, a question that teaches new concepts related to robot motion. In that question, students must read for understanding three descriptions of robot motion and apply them within a constraint—the sensitivity pattern of the robot's flame sensor. This question suggests that teachers can stress the importance of careful reading, understanding of parts of problems, and synthesis of knowledge when developing a solution. Q4 proved to be out of the reach of junior students; however, the subjects it covers (potential energy, efficiency, energy balance, trigonometry) are covered in high school science courses. To solve such problems requires integration of knowledge from these areas. We believe that teaching for understanding necessarily presents students many problems that require integration of knowledge.

Our experience indicates several areas for improvement. First, we have opened the Olympiad to teams of all levels of background, from junior-high students to university students. Recognizing that it is inappropriate to give the same test to all students, we will give exams at two different levels in 2006. Furthermore, we will prepare a study guide that will be posted on the TCFFHRC website, and we will encourage teachers to focus on challenging their students by assignments and tests that require students to integrate knowledge as an everyday exercise.

## References


1. D. Ahlgren and I. Verner "Integration of a Fire-Fighting Robot Contest in Multi-Level Engineering Education", Proc. 2001 ASEE Annual Conference, Albuquerque, NM.
2. L. Vygotsky (1978) Mind in Society. Cambridge, MA: Harvard University Press.
3. Trinity College Fire-Fighting Home Robot Contest: http://www.trincoll.edu/events/robot/.
4. Botball Program & NCER: http://www.botball.org/.
5. International Robot Olympiad: http://www.iroc.org/.
6. K. Garrison and R. Magoon (1972) Educational Psychology: An Integration of Psychology and Educational Practices, Merrill Publishing Company, p. 629.
7. D. Perkins "Teaching for Understanding", The Professional Journal of the American Federation of Teachers; 17(3), 28-35, 1993
8. C. Unger "What teaching for understanding looks like", Educational Leadership, 51(5), 8-10, 1994.
9. Project Zero at the Harvard Graduate School of Education: http://pzweb.harvard.edu/.
10. International Science Olympiads: http://olympiads.win.tue.nl/.

11. National Engineering Aptitude Search (NEAS): http://www.jets.org/programs/neas.cfm .
12. Barrett, J. (2003) The Aptitude Test Workbook, Paperback.
13. D. Ahlgren. "New Directions in Fire-Fighting Robotics." Presented at ASEE Annual Conference, Portland, June, 2005.
14. I. Verner and D. Ahlgren, "Robot Contest as a Laboratory for Experiential Engineering Education," ACM's Journal on Educational Resources in Computing (JERIC). Special Issue on Robotics in Undergraduate Education, Part 1, 4(2), 2-28.
15. C. Stein, "Autonomous Students Engineering Autonomous Robots." In Proceedings of the ASEE Annual Conference, Montreal Canada, June 2002.

**Biographies**

Igor M. Verner is a Senior Lecturer and coordinator of teacher-training programs in technology/mechanics at the Department of Education in Technology & Science, Technion, Haifa, Israel. In 2005-2006 he worked as a Visiting Professor at the Tufts University and a Visiting Scholar at the University of California, Berkeley. His research interests include experiential and situated learning, cognitive and affective development, design projects and robot competitions. Dr. Verner received the M.S. degree in mathematics from Urals State University and the Ph.D. in computer aided design systems in manufacturing at the Ural Technical University, Sverdlovsk, Russia.

David J. Ahlgren is Karl W. Hallden Professor of Engineering at Trinity College and is Director and Host of the Trinity College Fire-Fighting Home Robot Contest. Professor Ahlgren has been a faculty member at Trinity College since 1973, and he served as department chairperson from 1990-1999. His scholarly interests lie in robotics, modeling and simulation, and broadband communications amplifiers. Dr. Ahlgren received the B.S. in Engineering from Trinity College, the M.S. in Electrical Engineering from Tulane University, and the Ph.D. in Electrical Engineering from The University of Michigan, Ann Arbor.

David P. Miller is the Lester Wilkonson Chair and Professor of Aerospace & Mechanical Engineering at the University of Oklahoma. He also serves as the chair of the technical committees for KISS Institute for Practical Robotics, which administers the Botball program and the NCER conferences. Miller's research interests are the tradeoff between mechanical and software design for making capable robot systems for space exploration and assistive technology. Dr. Miller received his B.A. in Astronomy from Wesleyan University, and the Ph.D. in Computer Science from Yale.