THE MAKING OF ENGINEERS: THE ROBOT CHALLENGE
By Neville Jacobs

INTRODUCTION

The purpose of this presentation is to describe two IEEE initiatives that we believe can raise the interest of students in technology and engineering, counter the influence that television has exerted in glamorizing careers in other fields, such as medicine, law and high finance; and introduce students to the fun of getting involved with engineering challenges . We all know that engineering can be very exciting and rewarding, but we need to bring this to the attention of our pre-college students, so as to obtain a larger proportion of them going on to Engineering schools.

TWO SYMBIOTIC PROJECTS:

TISP - TEACHER IN-SERVICE PROGRAM

This is an enrichment program that IEEE started 2 years ago, and whose purpose is to expose students at every level to technology projects of about 2 hours duration. The projects would conform to, and be part of the ongoing school science and math curriculums. I will not dwell on this program, as I'm sure that others at this conference who will be talking about it. I see it as a key way to start getting a greater number of students, of all ages, familiar with what technology is all about.

THE ROBOT CHALLENGE.

This is an initiative from the Baltimore, Maryland, Section of IEEE, and is now in its 13th year. The purpose is to expose teams of boys and girls in High School (grades 9 though 12) to all the elements of an engineering project, so that they can really see if this is the sort of challenge they would like to have in their future careers. While educational, it is also fun and exciting, and can be done as part of their curriculum, or as an enrichment project after school. It involves 2 to 4 months of class time, kits are simple and inexpensive and are readily available in the US (or you can make them in your own country).

HOW THE ROBOT CHALLENGE BEGAN AND EVOLVED

The project was developed in response to a request from the Baltimore Museum of Industry, and our engineers set out to create something that would be as faithful to a real engineering project as possible. A walking robot was selected as the theme. To add some excitement, we made it somewhat (but not overly) competitive. To get wider participation we kept the cost down by building most of it from very basic materials, such as pieces of wood, threaded rods, paper clips, cheap motors and brass fasteners. Two years later the documentation was finished, and it was ready to be tried out.

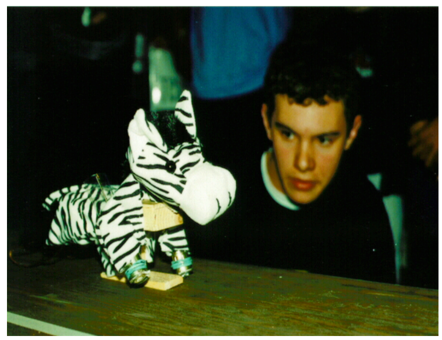

Figure 1 2-Leg Robot

Figure 1 shows a finished operational 2-leg robot. Surprisingly, though all robots are built using the same manuals, this finished robot will be different to any other 2-leg robot in the competition, and will behave differently as well (details later).

Over the years, the design has been improved and expanded, such that a team or teacher seeking more challenge can go beyond the 2-leg robot, and build a 4-leg robot, or develop more electronic and programming skills and build an automated 2-leg or 4-leg robot. Hence there are projects of increasing complexity for each year of high school, and all teams can compete together at the annual Event. Figure 2, shows a picture of a 2-Leg robot with the Automation controller on the right and the manual control on the left.

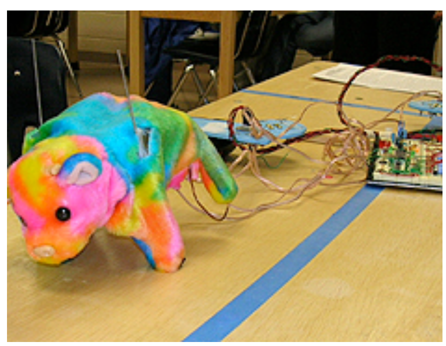

Figure 2 2-Leg Robot with Automation

There are no prerequisites for participation in the Robot Challenge, and it is open to any team of students of high school age. A team that completes their robot, gets it operational, and participates in the Challenge Event is considered a winner, and by keeping scores at each event we give them the means of comparing their performance with that of their peers. The final results, as well as photos of all participants, are posted on our web site, www.robotchallenge.com.

THE CHALLENGE

The design of the robot is purposely marginal, so that not only is it difficult to build perfectly (see Figure 3), but each robot is almost certain to encounter problems that will create troubleshooting opportunities similar to those an engineer will encounter. The judges grade how teams cope with these problems, especially when the team is under stress as it participates in the Track (or Demonstration phase) event.

It should be noted that the Robot Challenge is not a simulation of an Engineering project. It is an actual project by itself, just smaller in scale, and manageable at a school level.

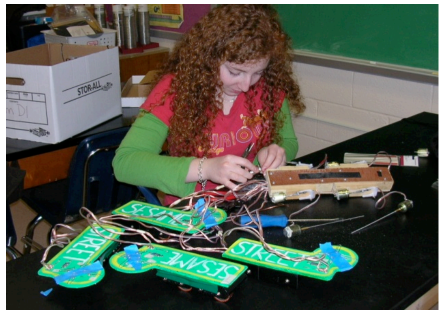

Fig.3 Working on a 4-leg Robot

COMPARISON WITH A REAL ENGINEERING CHALLENGE

There are typically 4 key elements to an Engineer's project, They are described below, and are followed by the equivalent elements in the Robot Challenge

ENGINEERS DEVELOP A NEW PRODUCT

Phase 1: The idea for a new product.
This may come from a customer request, from a department head, or from an engineer on the floor. Funding will be needed to produce a prototype. This will require that a document be prepared for Upper Management outlining the projected market, costs, sales projections and an estimate of what it will take to develop the prototype.
If the material is presented convincingly, it will result in the approval of the project

Phase 2: The implementation of the prototype
This involves design, development and test programs, with careful attention to detail. Deficiencies are corrected.

Phase 3: Evaluation
This requires measuring against a known set of conditions, or matching the prototype against competitive products

Phase 4: Presentation to Upper Management and/or Customers
This involves presenting the prototype and test data, and explaining the positive and negative aspects of the product. Hopefully it will show how the deficiencies can be corrected, so that the product can be launched into production.

These are the corresponding 4 phases for the Robot Challenge project:

STUDENTS' PROJECT

Comparable to Phase 1 is the Written Report,
In our case this is done after the product has been built, but before it is demonstrated. This 30 to 35 page document will have the same level of detail as an engineers proposal, but since students lack the experience of an engineer to forecast what will be done, the Written Report documents everything the team has already done to build, test and learn to walk their robot. This is their very own experience and not one that can be copied from a book or obtained from the internet. The Written Reports are examined by a panel of Judges, and evaluated to 10 criteria, including grammar, neatness, layout, illustrations, charts, content, and ease of reading

Comparable to Phase 2 is the construction of the robot and the design of the robot outer body.

This hands-on process will go on for 2 to 4 months (3 to 4 hours a week). Two manuals are available to guide their work, and all the information needed to implement the project is there - so long as the students read them carefully.

Comparable to Phase 3 is the Track event
Here is where the robots meet their competition for the first time, The course is 6 foot long, and there are two obstacles 1/2 inch high, that the robot has to walk over. Two robots run side by side on each 8 foot by 30 inch wide table (see Figure 4). The teams are graded on about 10 characteristics, including how well they perform as a team, their handling of the obstacles, and the time they take to complete the course. If the students are participating with automated robots, they must first complete the course in the manual mode, then do a run in the automated mode.

Fig.4 Phase 3 Track Event

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Phase 4 is the Oral Presentation before a panel of Judges
Here the students get an opportunity to explain all the good things that happened, and what went wrong. In the discussion with the judges they learn how they could have built the robot better, and improved their Track run. The Judges evaluate the teams in 8 categories, including the manner of the presentation, the ingenuity of the robot design, the workmanship and the quality of the soldering.

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WHY PROVIDE FUN AND EXCITEMENT

As mentioned earlier, we are competing for students who are also considering careers in law, medicine and finance, among others. Television makes these activities exciting, but we don't have similar programs in Engineering (maybe that's what we need!)

School and College counselors tend to be rather stuffy in describing the requirements to be an engineer; they emphasize the hard work, high level of math and the frustrations that accompany the job. While certainly true at times, we all know that Engineering can be very exciting, so we have tried to give the students periods of frustration but also periods of exhilaration, fun, and above all the satisfaction of accomplishment.

HOW DOES THIS MEET S.T.E.M.. REQUIREMENTS?

With regular assessments to assure that every student achieves technical excellence, school curriculums are seeking to encourage more participation in Science, Technology, Engineering and Mathematics (STEM), Many concepts used in this project come directly out of Science textbooks, though the students might not recognize this. Teachers do, and are thrilled with the improved essay writing and verbal presentation skills, as well as the electrical and mechanical concepts and the practical applications of the center of gravity - as in when the robot topples over! Technology is used throughout, Engineering is in the planning needed, and Math is kept practical - mostly used in the adding and subtraction of fractional measurements, making decisions on the leg lengths, calculating current flow, identifying the locations of counterweights, and during programming (for the more sophisticated robots).

Not surprisingly, students are not too thrilled with preparing the long Written Report and the Oral Presentations, but they recognize the need for them, so they reluctantly invest the necessary effort to get them right. Their joy is in the construction, the handling of tools, and participating in the Track event with all the other teams, even if they don't do as well as they would have liked.

It should be noted that over a third of our participants are girls, and they become just as adept as the boys in the use of power tools, and do especially well in soldering.

TEACHERS

They provide the support and encouragement of the students as they go though the frustrations and successes of the program (parents can sometimes help too). It is important to note that the teacher never provides the answer to their students' questions, but simply steers them in a direction which will allow them to obtain it themselves. In this way the project is different and more challenging than other engineering projects (such as FIRST).

Some teachers get very involved in the process, but others keep a hands-off attitude, and let the student teams work alone, reporting weekly to the class body by means of Power Point presentations. Knowledge of the project, however, is a plus, and we encourage teachers to attend our 4 hour training sessions, or better yet build their own robots during teacher enrichment programs (this requires 5 mornings)

If the program is further enriched with essays, discussions, assignments and tests by the teacher (so that the students develop a broad understanding of the science and math principals involved), we consider the course to be an Honors program for University admission purposes.

KITS

Figures 5 and 6 show the Robot kits and the Automation kits, and they are available for purchase in the USA. Kits contain everything needed to build the robots, other than the tools, the batteries, and the materials for the robot's outer covering.

Fig.5 Basic 2-Leg Robot Kit

Of the 30 items in the parts list of the basic robot, most can be made up locally, and details are provided in the manuals. Only 2 items in the Robot Manual are custom made (items 3 and 4), and these are now available through a distributor. One IEEE section is in the process of converting the dimensions in the manual to metric, and we hope to have this information available shortly

The Automation kits are also available in the US through the IEEE, and should not be hard to copy locally. We can provide purchasing data if needed.

Fig.6 4-Leg Automation Kit

These products should be distributed only through the IEEE, so any commercial house commissioned to build them should do so with the understanding that they are not to be made available for commercial sale to the public, unless approved by the IEEE (contact Nevilleed@aol.com).

Each section should decide on their form of distribution of kits and manuals to the schools and the price they will charge for them. They may elect to set prices to just cover their costs, choose to subsidize the schools, or use the project as a fundraiser.

The IEEE Baltimore Section has chosen to give away a 2-leg Robot Kit to every school that requests them. Subsequent kits are distributed at the cost we pay our supplier, or a little below in the case of the Automation kits.

MANUALS

The Robot Manual contains information of the science behind the various aspects of the project, as well as instructions and sketches to guide students in the construction of their robot - there is even a section on the reading of mechanical drawings. There is also information on how to prepare for the Written Report and Challenge Event. Teachers are free to expand on the background material from their current textbooks, but there is enough information in the manual that it can become the sole document for the course.

The Automation Manual is for more advanced students, and is not as comprehensive. There are more computer options available, and the teacher may need to get more involved with the steps the students should follow, in order to achieve consistent results.

Both Manuals are Copywrited by the IEEE, so you may have them printed locally, but they should only be distributed through the IEEE.

MENTORS AND JUDGES

IEEE members in Baltimore act as mentors and also become the judges at the Challenge Event. This year's 2-day event with 51 teams and over 200 students required 70 judges and support staff - all volunteers. Judges are guided by score sheets with criteria that assure that all scores and evaluations will be objective and consistent.

Mentors are required to understand the manual thoroughly, and to have been a Track or Oral Presentation judge on at least one occasion. Most mentoring is by e-mail, but occasional school visits are required. All teams are required to report to their Mentors at least every two weeks during the construction of their robots.

A Written Report judge must have been a Track or Oral Presentation Judge on at least one occasion. A Track or Oral Presentation Judge requires no previous experience, but receives 30 minutes of training at the start of the day's event, as well as the support of an experienced judge during his (or her) first hour of judging.

At the Challenge Event, the Judges meet the students for an exciting day. The students have many different backgrounds and skills, some are well prepared, other less so. A First Aid station (called the Pit) is provided for any robots that require assistance, so as to assure that every team will have the opportunity to participate fully.

SCORING

Custom Score sheets are used for each phase of the project, and designed to provide objective and consistent grades even with new judges. All information, including the sheets themselves, are kept confidential, so that judges can score and comment freely on the performance of the teams, These evaluations are later reprocessed in more appropriate language, and mailed to the students as feedback.

Scores are added up, scrutinized for errors, and published in descending points order on our web-site, the evening of the last event.

Team prizes are certificates and trophies and are distributed by mail to the schools. Every student receives a Certificate of Participation.

STUDENT BENEFITS

Scores above the median look good on a University application, since many of the schools participating are well known to college admission officers. An outstanding performance clearly benefits teams from schools that are less well know, since they can now provide objective evidence that their students are as good as or better than those from the elite schools. Two students from such schools received scholarships to prestigious universities last year, largely on the basis of their performance at the Robot Challenge.

COSTS

We offer a 2-leg Robot kit for $49 in the US, and a 4-leg kit is $88. For automation, the additional 2-leg kit costs us $109, and we offer it to our schools at $89. A 4-leg automation kit costs us $138, and we offer it at $118. The number of students in a teams can vary, though the average is about four. Students are expected to provide their own D-cell alkaline batteries (8 for a 2-leg robot, 16 for a 4-leg)..

For evaluation purposes, costs can be best considered on a student per month basis.

For the 2-leg robot, the cost is $6
For a 4-leg robot, the cost is $8
For a 2-leg automated robot, the cost is $10
For a 4-leg automated robot, the cost is $12

A workshop with power tools is helpful but not essential. The project can be implemented with a hand saw, electric drill, a pair of screwdrivers, a diagonal cutter, needle-nose pliers, a wire stripper, a hacksaw, sandpaper, a bottle of glue, paint, and a soldering iron. The Automation controller requires a low-wattage soldering iron, a small vise, and access to a computer (can be an old model). A voltmeter and Dremel tool with cutting disks are nice to have available.

Administration costs for running the Robot Challenge would depend on whether a school or museum can provide a room at no charge and whether volunteer labor is available. Costs are typically the kits and the manuals, and their price levels determine whether the section will take a loss or make a profit. Other than printing, mailing, table rental and awards, costs are mainly for snacks for the volunteers. The Baltimore Section's policy of subsidizing the first kit to each school has resulted in an annual expense of about $3900 over the past 7 years. However, the Baltimore Museum of Industry, where the Challenge Event is held, has some additional expenses (printing a program, T-shirts, trophies, snacks and salaries) from setting up all of the other Challenges that are held there every year. The Engineering Society of Baltimore raises funds for these activities.

WHY BOTHER?

The project is a lot of work, but it has three benefits.

It is a great project for both technical and non-technical students, and is one of the most popular Senior electives at our (non-technical) school. The students who complete it tell us they have learned a great deal from this hands-on approach to learning; those who sign up for it the following year, say they are doing it on the recommendation of the previous year's students.

Helping out with Mentoring and Judging is a great activity for IEEE membership, and fulfills the requirement of our charter that we provide technical support for our communities. I have not heard of a single judge who did not enjoy working with the students at the Challenge Event.

CONCLUSION

Taken overall, we've found that about

30% of the students participating were already planning on a career in Engineering - the project reinforces the decision for most of them, though a few find that it is not what they expected.

30% of the students come in with no intention of becoming engineers, and just enjoy the project, learn from it, and have fun.

40% of the students come in with their major undecided, and take the course to help them figure out what they should do. A significant number of these students do decide to become engineers, and these are the students that will tip the balance and help us increase the percentage of students selecting engineering in the future.

It is just as important that the project allow a student to find out that he or she is not suited to engineering (and not waste his time and money before switching to another major), as it is to help those who were considering other career pathways, but now discover that Engineering is what really turns them on.

GETTING STARTED

If we have at all succeeded in stimulating your interest, here are a few hints on getting started:

1. Make the IEEE Section the focus of the operation, find someone who will lead the operation, and 4 people who will agree to become mentors and assist in the planning.
2. Invite all officers and Board members to become judges, set up a preliminary budget, and decide the place and date for the first Challenge event. As a rough rule of thumb, you will need about as many judges and support staff as you have teams.
3. Learn about your school system, determine whether they have wood workshops and tools available. Consider groups other than schools that might be interested in participating, such as Home schools, Boy Scouts, Girl Scouts, etc. Set modest objectives for the number of teams that will participate the first year. .
4. Obtain a supply of kits. You may find it easier to purchase kits in the US for the first year. We require 2 months notice if a significant number of kits are required.
5. Start with just 2-leg robots (and possibly a 4-leg team or two), Be sure the teams begin working on the robots at least 2 months before the date set for the Challenge
6. For the Challenge Event you will need tables 8 feet long by 30 inches wide for the Track event, and 6 x 3 foot tables and 6 chairs - preferable in separate rooms, for the Oral Presentations You will need one Track table and one Oral Presentation room for each 6 to 8 teams participating.
7. Order a set of score sheets and a layout of the Track table from the IEEE Baltimore Section (Nevilleed@aol.com)
8. Enjoy!.

RECOMMENDATIONS:

Talking to the more than 3000 students during the Oral Presentations we have the impression that we have made a significant difference in the number of students taking up engineering as a career. We urge other sections to review this material and try the Robot Challenge at their own schools.

ABOUT THE AUTHOR

Neville Jacobs was born in Buenos Aires, Argentina, and went to Bryanston School and Oxford University in England where he obtained an MA in Engineering Science. Returning to Argentina, he worked for SIAM de Tella Ltda for 8 years, then came to the USA in 1963, where he joined the Westinghouse Electric Corporation, working in various divisions as Manager of Quality Assurance, Reliability and Test. During this time he was active in company Discover-E programs, the Baltimore Museum of Industry Engineering Challenges, and trained technical staff in trouble-shooting. He retired in 1995, and with an associate worked on the design of the Robot Challenge. A few years later he was invited to become a high school teacher at a private day school, and developed a course for Seniors (12^{th} graders) called Introduction to Engineering, which he still teaches and which includes this project. He is a past board chairman of the Society of Reliability Engineers, past chair of the IEEE Baltimore Section Reliability Chapter, and is currently Director for Student Activities for the section, where one of his tasks is organizing the annual Robot Challenge event. In 2005 he received the Meritorious Service to the Engineering Profession award from the Engineering Society of Baltimore.