Design and Implementation of a Project-based, High School Robotics Class
Marc Allard
Menlo School
marc.allard@menloschool.org

Design and Implementation of a Project-based, High School Robotics Class

Introduction

Since 2008 I have been teaching a robotics course entitled *Electronics Robotics* at Menlo School. Menlo School is a non-sectarian, co-educational, independent school located in Atherton, California. The upper school (grades 9 through 12) is comprised of approximately 580 students. *Electronics Robotics* is an elective course for grades 10 through 12, and much of the course revolves around participation in FIRST's FTC robotics competition. While our students have had success in the competitions, I am not altogether convinced that the objectives of FIRST are congruent with the objectives of my course and, as such, I am exploring the possibility of competing in BotBall. This paper describes the objectives and curriculum of my course.

Course Objectives and Implementation

There are five objectives to my course. I will elaborate on each.

1. Students should have hands-on robot building opportunities in conjunction with programming.
2. Students should be given constraints in the form of competitions and challenges.
3. Students should learn the principles of robotics.
4. Students should learn about the applications of robotics in the world around them.
5. Students should learn how to work in groups.

Hands-on Robot Building & Programming

On the second day of school my students immediately start building their Lego robots. I feel it's extremely important that students actually *build* something in my class with their hands. After all, the fact that there is a robot *thing* that interacts with the physical world is what separates robotics from pure computer programming. Moreover many of my students have little-to-no experience with using basic tools, which, frankly, should be a graduation requirement. Whether it be Legos, Tetrix, wood, plastic, or metal, I try to get my students to interact with these parts and/or materials as much as possible. Bear in mind that this is not a very difficult objective to accomplish, as most students are eager to build things.

The reason I put *programming* as an objective along side *robot building* is that it is not uncommon to get students who prefer the latter and shy away from the former. To me this is just as problematic as programming without robot building. Understanding how to make a robot act based upon sensor input is critical to the fundamentals of robotics, and I tell the students that it's not okay to simply build a robot without being able to make it "come to life."

In my course the students program their Lego Mindstorms modules using RobotC. I have found RobotC to be accessible to all of my students, and it serves as a great introduction to the world of programming.

Constraints disguised as Competitions

My background is in mechanical engineering, and what I love about engineering is that it's all about constraints. The challenge in any design is figuring out how to make the best solution given the constraints. Anyone can design a widget if you don't have to worry about costs, materials, size, or the laws of physics. But as soon as you start adding real world constraints, that's when the creativity and ingenuity start going.

The beauty of robotics competitions is that they are constraints *disguised* as competitions. The students love competitions because they view them as opportunities to compete against other teams to see who will take first place. However the competitions are, in fact, objectives with constraints. The objective, of course, is to get the most points by doing task A, B, or C etc. The constraints are the rulebooks. After all, the rulebooks tell the materials, maximum weights, sizes, etc. which all together comprise the constraints and thus the opportunity for ingenuity.

In my class I frequently do "mini-challenges" to get the students to (a) get their competitive juices flowing, and (b) constrain the scenario to get their creative juices flowing!

Principles of Robotics

Most schools participate in robotics competitions by forming robotics clubs. My students are enrolled in a robotics *course*, and as such, they must do more than just build a robot. The textbook that I require for my course is *The Robotics Primer* [1]. This book is used for Dr. Matarić's introductory robotics course at USC, however, I have found it to be generally accessible to high school students (I cover approximately half of the book). Students are given quizzes for each chapter, and there is a comprehensive exam at the end of the semester. In course surveys students have overwhelmingly rated the textbook as their least favorite part of the course, however, at the same time they have acknowledged the importance of the content. I continue to explore alternative textbooks but for the time being, *The Robotics Primer* reigns.

Applications of Robotics

Robotics is not just an abstract topic in the classroom. Robots are everywhere, and my students need to understand just how pervasive they are. To this end there are three aspects of my curriculum that fall under the heading of "Applications of Robotics."

1. "Robot of the Week" – Each quarter every student must do a short oral presentation on a "real world robot." In the first quarter I typically hear about the "usual suspects," e.g.

Asimo, NASA Mars Rover, Roomba, etc. However by the third and fourth quarters, the students have to really start searching for more unique robots. This past year, in an effort to make things more challenging, I told them that of their four robots, one had to be from land, one from sea, and one from air or space. It's a great opportunity for students to gain an appreciation for the multitude of robots out there.

2. Robot Documentaries – There are two documentaries that I show the students that are well worth the time.

   The first is NOVA's *The Great Robot Race* [2] which chronicles the 2005 DARPA Grand Challenge. This video is particularly timely given that the winning team was led by Sebastian Thrun who is now working for Google on their autonomous car project.

   The second documentary I show my students is a 60 Minutes episode called *The Deka Arm* [3]. This inspiring video shows how Dean Kaman's firm, DEKA, is trying to develop a "bionic arm" for amputees from the military.

3. Company Visits – Because Menlo School is situated in the heart of the Silicon Valley, we are in close proximity to numerous robotics companies. I have managed to arrange two company tours in the past two years, and the students thought they were excellent. The first was at Willow Garage (Menlo Park), makers of the PR2 robot and ROS (Robot Operating System), and the second was at Intuitive Surgical (Sunnyvale), makers of the DaVinci Surgical System. I hope to increase the number of company tours next year.

Working in Groups

The last objective of my course is to give students an opportunity to work in groups. Working in a group with a common objective is an extremely important skill both in college and work. Students start the year working in pairs as they familiarize themselves with the Lego Mindstorms. A few months later the FTC competition begins and I divide the class into teams of approximately five students. I tell the students to select a team captain, and I emphasize the fact that the team captain gets the final say on team disputes. I regularly meet with the team captains, one-on-one, to discuss the progress of the team, and to see how the team dynamics are going.

A Typical Year

The rough flow of the school year is as follows:

August	Start of school. Work in pairs on Lego Mindstorms and RobotC.
October	Begin FTC competition. Teams of ~5 students. Build practice arena. Brainstorm. Build prototypes.
November – December	Compete at FTC qualifying events. Semester exam in December

January – February	More FTC qualifiers. FTC NorCals in late February (usually).
March – April	Prepare for FTC World Championships, or Begin Spring robotics project
May	Menlo Maker Faire (SumoBots) Maker Faire (SumoBots)

Challenges

Overall the course has been very successful. In four years of FTC competition, we have gone to the World Championships twice. Student engagement is very high and the course feedback is very positive. That being said, I am constantly evaluating my course and looking for ways to improve it. Here are some of my more pressing issues.

Poor Mechanical Skills

While I want the students to get "hands on" as soon as possible, their mechanical skills are horrendous. They don't know how to use fasteners, cut metal, or build basic assemblies (to name a few). I keep trying to allocate time for teaching of these basic skills, but it always falls down the priority list. The simple fact is that this shortcoming is rarely an impediment to success in the competitions.

Lack of Emphasis on Autonomous Mode in FTC

In the FTC matches, only the first 30 seconds is devoted to autonomous mode (the remaining 2 minutes is tele-operated). I believe this is a major shortcoming of FTC since it puts too little emphasis on what robotics is all about, autonomous operation. In fact, there are numerous teams that have no autonomous program at all and rely solely on tele-op. To remedy this, should I continue to participate in FTC, I intend to require *my* students to have a fully functioning autonomous program. Moreover, they must utilize sensors to provide feedback on which to make decisions and act. While this obviously will not be a requirement from FTC, it will be a requirement for my course.

Another solution to this problem is to abandon FTC and explore alternative robotic competitions. I am intrigued by what I have learned so far about BotBall, and I believe it could fit very well into my course curriculum. I will thoroughly explore this option at the International BotBall Tournament.

Yearlong Development of Programming Skills using Lego Mindstorms

In the past, once the FTC competition started, students stopped working with their Lego Mindstorms. As a result many students' programming skills became very poor. Next year I intend to have ongoing Lego projects for the entire year so that students can continue to develop their programming skills (and not forget them).

Uneven Distribution of Work

A common problem with any workgroup is keeping the distribution of work relatively equal. All too frequently one or two students will do the majority of the work while other students sit back and do very little. I do have team members complete anonymous surveys to rate the contribution of their teammates, which sometimes is enlightening, but sometimes is not. This is a work in progress.

Better Synchronization of Textbook with In-class Activities

At times the textbook material can be rather abstract, and it often runs independent of the in-class robot activities. It would serve the students well if the robot challenges incorporated principles from the textbook.

Conclusion

This paper has attempted to give an overview of the curriculum for my robotics course. I believe the course has been successful in that it has challenged students at many different levels while keeping them engaged. The course is not without its challenges, but with continued experimentation, hopefully it will evolve and improve.

References

[1] Matarić, Maja J. *The Robotics Primer*. Cambridge, MA: MIT, 2007.

[2] Seamans, Joseph, dir. "NOVA: The Great Robot Race." *NOVA: The Great Robot Race*. WGBH. 2006. Television.

[3] Cetta, Denise S., prod. "60 Minutes - The Deka Arm." *60 Minutes*. CBS. 12 Apr. 2009. *CBS News*. Web. <http://www.cbsnews.com/video/watch/?id=4937716n>.