Fun With Robots: A Student-Taught Undergraduate Robotics Course

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***Abstract* – We present a lab-based, student-taught robotics course at Carnegie Mellon University entitled *Fun With Robots*. The course does not require background knowledge of robotics, and students enroll from a wide variety of disciplines and education levels. *Fun With Robots* increases interest in robotics, and emphasizes the highly multidisciplinary nature of the field. In the course, students build a robot and learn basic elements of microcontroller programming, sensor use, planning, and manipulation through engaging projects. *Fun With Robots* is constantly evolving and has changed significantly over the six semesters it has been taught. This course serves as an introduction to robotics for students new to the field and links high school programs and advanced undergraduate robotics courses. Foremost, the course is intended to be fun; students are encouraged to demonstrate creativity and self-expression. Course materials are available via the web at http://www.funwithrobots.org.**

Index Terms – Robots, Education, Educational Technology, Mobile Robots, Robot Programming

INTRODUCTION

This paper presents tools and a curriculum for a student-taught introductory robotics course titled *Fun With Robots*. There are no prerequisites for this course, and no prior knowledge of robotics is required. This allows students from differing backgrounds and education levels to enroll in the course and gain knowledge about the field of robotics. As the course does not count toward graduation requirements, students enroll purely out of interest in the subject matter.

Although entrants come from diverse academic backgrounds and may have no prior robotics knowledge, students leave *Fun With Robots* with skills in basic microcontroller programming, sensor use, path planning, and robotic manipulation. In the labs, students work with a small two-wheeled robot, roughly the diameter of a compact disc. Students construct this robot from a kit comparable to the cost of an engineering textbook. The class is set in a computer lab and encourages hands-on experimentation, creative expression, and multidisciplinary interaction. In one lab, students complete a robotic art project. This lab encourages students from technical and non-technical backgrounds with complementary knowledge to interact. Enrollment in the course is very diverse and roughly reflects the demographics at our institution. Students are concurrently able to collaborate across disciplines, exercise self expression, and develop their robotics knowledge.

The central goal of *Fun With Robots* is to increase interest in robotics. As the course is offered on a pass/fail basis, students worry less about grades and more about learning and experimenting with their robot. The only requirement to pass the course is for students to complete all labs. In this way, the course is accommodating to students with different levels of experience and background knowledge. Though there is no strict grading policy, the instructors have found that many students go out of their way to challenge themselves. The robot kits in the course are flexible enough that advanced students can progress beyond the bounds of the assigned tasks. At the same time, the instructors can provide extra assistance to those struggling with the labs.

The structure of *Fun With Robots* enables the course to change easily. Students purchase their own robot kit and keep the robot at the end of the semester. As technology improves, the instructors are free to change parts or even the entire robot kit between semesters. This allows for the evolution and enrichment of the course curriculum. In addition, the curriculum for this course is modular, allowing the order and content of the labs to change without significantly affecting other parts of the course. Due to this flexibility in the course tools and curriculum, *Fun With Robots* quickly evolves with changes in technology and student interests.

This paper continues with a background of the current robotics education landscape and the niche *Fun With Robots* fills. We then describe the evolution of the course to date and detail the current curriculum and robot kits. Following is a discussion of our experiences and observations from offering the course. Finally, we discuss how the course is adaptable to other academic settings.

BACKGROUND

Fun With Robots incorporates elements from both collegiate and high school level courses. By comparing and contrasting our class with a sampling of other robotics courses, we seek to highlight how *Fun With Robots* fits in the scope of robotics education.

Many robotics courses are taught at the undergraduate level. For example, *General Robotics* at Carnegie Mellon University seeks to educate students about a range of robotics topics [1]. Primarily engineering and computer science students take the course. Our course focuses on similar topics, but at a more basic level, allowing students with no background knowledge to enroll. *General Robotics* and other courses such as MIT's *6*.270 [2] use LEGO® kits and Handy Board microcontrollers. While the high initial cost of this combination can be amortized, *Fun With Robots* seeks to allow students to keep their robot, and thus does not use this platform.

Researchers at Bryn Mawr and Swarthmore Colleges have developed a course which uses robotics laboratories to teach artificial intelligence (AI) concepts [3]. The course frames topics in AI as robotic tasks, and students construct and program robots to complete the tasks. Although the course is similar in that students of varied backgrounds can enroll, *Fun With Robots* presents a broad array of robotics topics rather than focusing exclusively on artificial intelligence.

A course developed at the University of West Florida emphasizes the multidisciplinary nature of robotics [4]. Topics covered include kinematics, dynamics and control, and robot design. At the end of the course, students design a robotic device for a competition. The course is intended for senior undergraduate students as preparation for graduate robotics classes. Although *Fun With Robots* also emphasizes the multidisciplinary aspect of robotics, our course is accessible to college students of all years.

Programs to educate students at the middle and high school levels also exist. FIRST robotics competitions present students with a yearly engineering design problem [5]. This program pairs students and professionals together, letting students gain valuable real-world experience. Botball, an engineering outreach program, is intended to excite middle school and high school students about computer science, math, and engineering [6]. Students design, build, and program autonomous mobile robots for the Botball competition. Another competition-based initiative for educating young students is a division of the international RoboCup [7] tournament called RoboCupJunior [8]. The competition offers opportunities for students at many ability levels to develop their skills in science and engineering in a diverse and cooperative environment. *Fun With Robots* integrates many of the desirable aspects of these programs including practical experience, collaboration, and a competitive atmosphere to inspire excitement and motivation. However, these high school programs are large group projects with mentors from industry. Students in our course work alone or with their peers in small teams of two or three.

Similar to existing undergraduate courses, the *Fun With Robots* curriculum contains lessons and lab projects, with much of the learning occurring during the labs. Like the secondary school programs described, *Fun With Robots* strives to achieve the broader goal of fostering interest in the field of robotics. The course bridges a gap between high school and college robotics education, providing an opportunity for students to receive robotics instruction early in their collegiate career when they may not yet meet the prerequisites for advanced undergraduate courses. Simultaneously, *Fun With Robots* provides a chance for non-technical students inexperienced in robotics to learn about robots in a relaxed environment. This non-traditional classroom setting encourages experimentation, creative thinking and collaboration between students. *Fun With Robots* also seeks to increase student awareness of the role robotics plays in other disciplines and to help students value multidisciplinary problem solving.

Course

A. Course Evolution

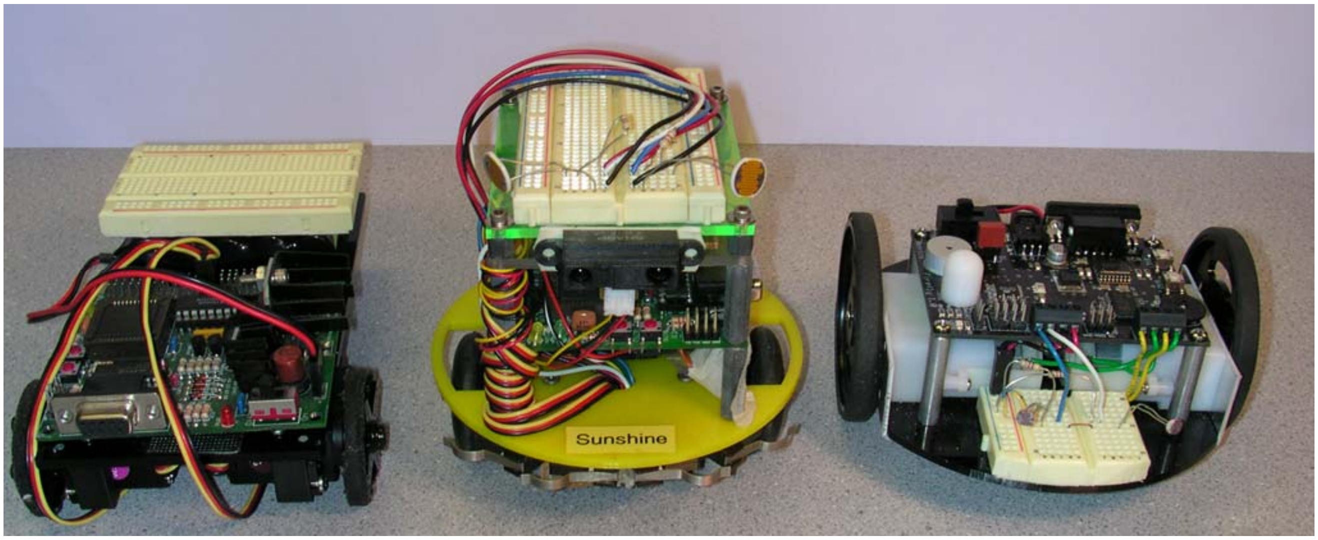
Fun With Robots has evolved over the six semesters it has been taught, shifting focus from ground-up robot assembly to robotic applications. We present this evolution to highlight how the course structure has allowed adaptation as technology changes and students' needs are better understood.

The class was first taught in the fall of 2002 by Brian Kirby and Tom Lauwers, who conceived the initial curriculum. Each semester, attempts were made to improve the course; some were successful, and some were not. Early versions of the course spent a significant portion of class time on robot assembly. To save on costs, each student assembled his or her own microcontroller by soldering components onto a pre-designed board. Although this provided students with valuable experience, the assembly process consumed half of the semester. While student response during this initial semester was positive, most expressed desire to spend more time exploring robotics concepts and less on the minutiae involved with building robots.

Many shortcomings of the early versions of the course were solved because the course is responsive to changes in technology. The issue of soldering the microcontroller was solved by advances in microprocessor technology and cost reductions in assembly, which allowed students in recent semesters to be supplied with pre-assembled boards for little extra cost. Another problem in the robot assembly process was the need to modify model airplane servos for continuous rotation. This step proved very frustrating as small mistakes were often unrecoverable. Availability of inexpensive pre-modified servos solved this problem.

The robot platform has also been altered to be more compatible with lab requirements. For example, the robot used in the first semester (Fig. 1a) had an undesirably large turning radius, making maze traversal difficult. This provoked a significant mechanical change to the robot platform (Fig. 1b). Improving the cost-effectiveness and speed of the robot by switching to a new drive train and microcontroller led to the current robot (Fig. 1c).

Many of the early labs were successful enough that they are still being used today with only minor changes. For example, a photovore (light-following) and maze navigation project still have a place in the curriculum. Other labs taught



(a) Original robot *(b) Intermediary Robot* *(c) Current Robot*

Fig. 1: The evolution of the robot

in more recent semesters are completely new, such as the robotic art project.

In addition to changes in the curriculum, the course logistics have also undergone transformations. The location of the primary workspace was changed from a small room with few computers to a university computer lab. With more computers, students no longer have to share a computer or wait to program their robots. Numerous hardware changes now make it possible for students to assemble their robot in one class period. Thus, the students own a working robot very early in the course, increasing their excitement and leaving more time for experimenting with their robots.

There have also been changes to the number of teachers for the course. In the past, there have been two teachers for a class of 30 students. Currently, three instructors teach *Fun With Robots*. We have found that the lower ratio of ten students per instructor facilitates learning and allows students to get individualized attention tailored to their needs.

The primary result of these changes was to alter the focus of the course from making robots to using robots. Students have more fun when they can see the rewards of their work early in the semester. Time that would otherwise have been spent arduously assembling the robot can be spent learning and playing with them. Through this course, students are given tools to pursue their robotic interests further as they learn how robotics and their chosen discipline interact.

B. Course Overview

In its current form, *Fun With Robots* continues to be taught by undergraduates. Over 200 students have taken and completed *Fun With Robots*, with class sizes hovering just under 30 students. The course is graded on a pass/fail basis; students must complete all of the labs to pass. Enrollment in this course is voluntary, as students receive no credit towards graduation. As in the past, the course meets once per week for two hours. In addition, it is expected that students spend one to two hours per week outside of class on their robot. To date, the course has been taught eight times in six semesters.

The course takes a "tell me, show me, let me do it" approach [9]. First, instructors propose ideas and provide background material to pique student interest. Next instructors introduce a lab project with the robot kits and show a working example. Finally, students work on the labs. Most learning in the course occurs through the lab activities. In labs, students build sensors for their robots to explore their environment. Students are taught the basic circuit elements of the sensor, and how useful data can be derived from these elements. Because students work with real robots in the course, they gain experience dealing with real world robotics issues. Students must deal with inconsistencies in sensor data, memory and processor constraints, physical limitations of the robot and sensors, and dynamic environments.

Since *Fun With Robots* is taught by undergraduate students without major funding sources, the course runs with as little overhead cost as possible. *Fun With Robots* receives an educational grant to help subsidize the cost of student robot kits. To run the course, an extra US$150 is required to purchase soldering irons, solder, screwdrivers, and glue. Most of these materials are reusable, so this cost can be amortized over each section taught. In teaching the course eight times, we estimate only US$1 has been spent per student for these materials.

C. Robots

Students in this course build a mobile robot with several sensors. Designed by Botrics, LLC [10] specifically for our course, the robot has a circular base 13 cm in diameter and stands 8 cm tall on two wheels and a caster (Fig. 1c). The robots use low-cost but fully functional microcontroller boards based on the ATMEL® ATmega168 microprocessor. This board provides six general-purpose ports, all of which can easily be interfaced with off-the-shelf sensors or homebrew sensors constructed in class. Additionally, the board drives two DC motors and has two programmable buttons, a potentiometer, an RGB LED, a piezo buzzer, and RS-232 and I2C ports. Also included in the robot kit are photocells, IR transmitters and receivers, and a model airplane servo. The cost of a robot kit is comparable to that of an engineering textbook.

Programming the robots is straightforward. Students write, compile, and download C code to their robot via a serial cable without a special adapter, using a free open-source package called WinAVR [11]. Because the components of WinAVR are platform-independent, students running Windows®, Linux, or Mac OS X are able to work on their robots outside of class if needed. We augment this software package with a custom library to further simplify robot control. Instead of overloading the students with details of interrupts and timers, this library includes simple functions which control discrete robot actions such as motor control and sensor input. This programming method makes *Fun With Robots* accessible to students with little or no programming experience, while still allowing challenges for more advanced programmers.

D. Labs

Fun With Robots takes a laboratory-based approach to teaching robotics. The approach involves giving students a robot to assemble, adding sensors, and providing increasingly complex challenges. Students are left to work on their lab assignments in teams, or alone if they choose. The lab projects are designed to teach different aspects of robotics in a fun and accessible way. Table 1 provides a summary of some of the labs used in *Fun With Robots*. Since the course is modular, the instructors can add or rearrange labs without affecting the overall course structure. To show an example of lab structure, an expanded description of the maze navigation lab follows.

Four lab sessions are spent on a maze navigation competition evaluated on speed and planning efficiency. Using two phototransistor-emitter pairs, students must explore a complex environment. While the sensor input as seen by the controller is nearly the same as in other labs, students are challenged to interpret the data in a more sophisticated manner. From these data, students infer the placement of the walls of the maze in order to complete it as quickly as possible. Robots are run head-to-head in mirror images of the maze on competition day. The competition motivates students by offering prizes to the best robots, and does not penalize robots that fail on the first try. Students whose robots do not complete the maze are given more time to change aspects of their design and encouraged to try again. Though this lab is challenging, the competition seems to motivate and excite the students. Even though they are competing against each other, the students rely on one another for insights on solving the problem. By the end of the lab, students have covered sensing, path planning, reactive control, and robot locomotion.

One future lab planned for this course is RoboJoust, which has students' robots jousting with servo-mounted lances to knock a small figurine off an opposing robot. We hope this project, although slightly whimsical, will excite students while encouraging them to solve robotics problems in a dynamic environment. This lab is meant to be used towards the end of the semester as a culmination of all previous labs, requiring students to integrate all topics learned in the course.

More information about the *Fun With Robots* curriculum, including lecture slides, sample code, and lab descriptions can be found at http://www.funwithrobots.org.

Classroom Observations

Fun With Robots has consistently received positive feedback in end of semester course evaluations. Students report that they are satisfied with the course and have even requested extensions to the curriculum. Since students do not receive credit for *Fun With Robots*, we speculate that they continue to take this course because they are having fun with robots.

Enrollment in the course has remained consistently diverse, as shown in Figs. 2 and 3. In two recent course offerings, approximately one third of the students enrolled were engineers, one third were computer scientists, and the remaining students represented either the pure sciences, humanities, business, or fine arts.

Comparing enrollment data for the past two semesters to the overall demographics at our institution (Figs. 3 and 4), engineering students were equally represented in our course. Computer scientists were over-represented, while humanities and science students were slightly under-represented. It is notable for a class of this scope that the proportion of fine arts students enrolled in our course is nearly equal to that of our university. In our experience, the undergraduate robotics courses offered at our institution consist primarily of engineers and computer scientists. With occasional exceptions, humanities, science, business, and fine arts students are not represented at all.

TABLE I
Overview of the labs in *Fun With Robots*

Lab	**Description**
Photovore	Students make a simple photovore, a robot attracted to light. Teaches real world sensing non-idealities and basic circuitry.
Maze Navigation	Students compete in a maze navigation competition scored on speed and efficiency. Teaches reactive control and path planning.
Robotic Signature	Students design a unique robotic signature using a servo-mounted pen. Teaches robotic design concepts, encouraging creativity.
Robotic Art	Students build a piece of robotic art, utilizing their acquired robotics knowledge and their creativity. Past robots include an Etch-A-Sketch® robot, a dancing robot doing the hokey pokey, and a fractal drawing robot.

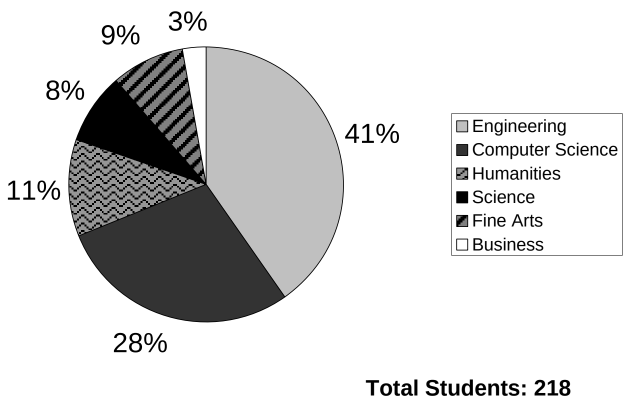


Fig. 2 Cumulative (2002-2006) *Fun With Robots* enrollment data.

Because students enrolled in our course are of varying disciplines, small multidisciplinary teams emerge that exploit the differing strengths of their classmates. For example, computer science and design students often have very different skill sets. However, since both skill sets are needed during this course, students learn to value and utilize each others' knowledge. In our experience, these types of interactions between majors are not common in many college environments.

The fact that students keep the robots they build adds value to the course. We have observed that ownership invites more innovation than when students are not afforded the opportunity to keep their own robots, as is the case in many introductory robotics classes. Ownership also implies responsibility; students quickly learn to diagnose problems with their robots, devising techniques of calibration, modification and repair. One semester, students were not permitted to purchase their robots, and we observed that many fine arts students subsequently dropped the course. Personal ownership of a robot appears to be particularly valuable, especially to non-technical majors.

As a separate observation, competitions seem to engage and excite students to learn. Students are awarded prizes for performing well, encouraging many students to work on their robot outside of class. They experiment with daring solutions they are unsure they can implement, without fear of being graded negatively against their classmates.

Students in *Fun With Robots* often elect to challenge themselves beyond the lab requirements. The course is structured so that students see the results of their work early in the semester. This encourages students to develop creative approaches to lab problems, and thus many students spend a considerable amount of personal time extending the capabilities of their robot. We believe they find this experience rewarding. The fact that students are free to challenge themselves and each other at will creates an enjoyable experience for all students, sustaining the "fun" factor of the course.

Every student can be successful in *Fun With Robots*. Often, success means something different for each student. For example, in the robot art lab, students define "art" in their own ways. One experienced student designed an Etch-A-Sketch® robot, while another with no prior experience was thrilled to master the use of the analog ports to receive sensor data. The two students achieved on different levels, and both learned from their experiences.

ADAPTABILITY

This course has successfully introduced many undergraduates from a variety of disciplines to the field of robotics. Because *Fun With Robots* only requires a computer lab and a minimal initial investment to purchase robots and a few basic hand tools, we believe that educators can replicate this approach to teaching robotics in a college or high school setting.

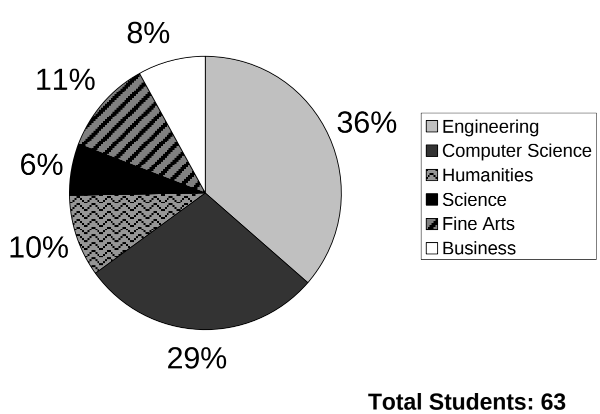


Fig. 3 Enrollment data for past two semesters of *Fun With Robots*.

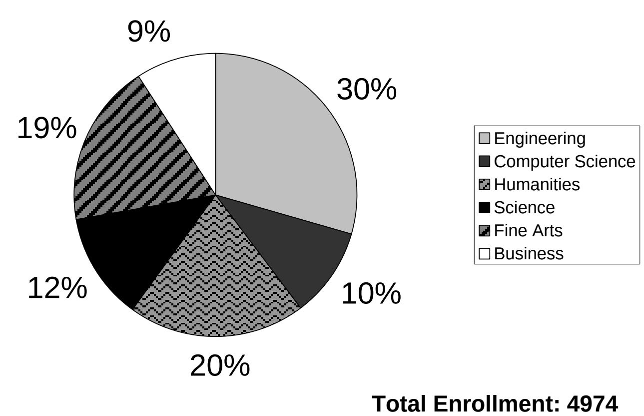


Fig. 4 Undergraduate enrollment data at our institution (2004).

Fun With Robots can be easily implemented in most universities due to the general availability of the resources it requires. The contents of the course curriculum can be expanded to create a more in-depth and intensive robotics course. In departments or colleges without an existing robotics curriculum, this course can be used to introduce students to robotics and gauge the receptiveness of the student body to a robotics-based curriculum. Those schools with an existing robotics education program can use this course to introduce robotics to students who do not traditionally take technical courses.

We also believe that *Fun With Robots* can be adapted as a high school course, a high school summer camp, or an after-school activity. Secondary educational institutions often have limited funding available, which may prohibit new courses or activities. However, the robot kits used in this course are inexpensive compared to many robotic education platforms available today. Although our course allows students to purchase their robots, high schools may opt to amortize this cost over several years by purchasing a classroom set of robots. The robots are durable, and can be reused from year to year. To further lower the cost, students may complete the lab assignments in groups of two or three.

CONCLUSIONS AND FUTURE WORK

We have described a student-taught course entitled *Fun With Robots* that makes introductory robotics education accessible to any student, regardless of previous experience or training. The course can be used to foster interest in robotics at the early undergraduate level. Through an innovative curriculum, students interact across disciplines, exercise creativity, and work in teams while learning robotics fundamentals. Many students enter the course whose disciplines seemingly have no relation to the field. However, it is increasingly the case that students find some aspect of their discipline relates to the field of robotics through this course.

The course structure facilitates straightforward modification and extension. The *Fun With Robots* tools and curriculum can evolve with changing technology and student needs. Further, the course is adaptable for different educational settings. The course can also be implemented for relatively little cost. For these reasons, the course model is versatile and widely applicable for high school and college environments alike.

We plan to continue designing new labs and evolving the robot kit as student wants and needs are further identified. We are starting to take a more rigorous approach to identifying these needs by deploying more formal course evaluation metrics to survey student learning, motivation, and satisfaction throughout the course. We hope that by conducting these studies and evolving the course based on measured need, students will continue to find the course innovative, accessible, and fun.

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