Final Report for NSF Grant DUE-9650969:

Robot-Based Explorations in a Liberal Arts Environment

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Project Summary

We have developed a new course at Wellesley College called *Robotic Design Studio*, which serves to introduce liberal arts students to many of the big ideas of engineering. In this course, students learn how to design, assemble, and program robots made out of LEGO parts, sensors, motors, and a palm-sized computer. The course culminates in a robot talent show where students exhibit the robots that they designed and built during the course. These creative projects tie together aspects of a surprisingly wide range of disciplines, including computer science, physics, math, biology, psychology, engineering, and art. The course, which has no prerequisites and has attracted students from a wide range of backgrounds, has been over-subscribed for the past two years. Additionally, we have experimented with using robot-based activities in existing computer science and physics courses. We have disseminated our work by organizing and leading several workshops for faculty and students at other liberal arts colleges and creating a website at http://www.wellesley.edu/Physics/robots/studio.html .

1. Introduction

The goal of our project was to develop an introductory robot-based design course in the context of a liberal arts curriculum that met the following desiderata:

- The course should expose liberal arts students, particularly women, to the excitement, spirit, and intellectual substance of the physical sciences and engineering through hands-on robotic design projects.

- The course should encourage explorations spanning a wide range of disciplines, including physics, computer science, mathematics, biology, engineering, and art.

- The course should be accessible to all liberal arts college students, with no prerequisites.

In pursuit of these goals we developed Robotic Design Studio, an intensive laboratory course in which students are first to the basics of robotics and then work in groups to design, implement, and exhibit their own robotic creations. We have now taught *Robotic Design Studio* over four January terms to almost 70 students.

In many ways the course has exceeded our wildest expectations. Hailing from 26 different departments and often coming without any prior programming or mechanical building experience, our students have created robots that surprise and delight us with creativity and ingenuity. The course has had high visibility and has generated excitement not only among Wellesley College students but also among the greater Wellesley College community and at other liberal arts colleges as well. In fact, faculty at several other liberal arts colleges are following our lead by adapting the *Robotic Design Studio* course to their home institutions.

After four years of teaching the *Robotic Design Studio* course, our view of its purpose has changed somewhat. Whereas we once thought of robots as a way to engage students in scientific investigations, we now view them primarily as a way to introduce liberal arts students to the "big ideas" of engineering in a liberal arts curriculum. Traditionally, liberal arts schools have considered engineering topics to be outside the scope of a liberal arts education. We argue that there are several important engineering ideas/dimensions that every liberal arts student should be exposed to, including: design issues, hands-on construction, systems-level thinking, abstraction, modularity, ideal models vs. the real world, resource constraints, and iterative development. These ideas were only implicit in early incarnations of the course, but as we have recognized their importance, we have started to distill them out of the course and teach them explicitly.

The issue of teaching engineering in a liberal arts environment has been brought to the forefront recently by the announcement that Smith College is starting an engineering department and degree program. We take this development as strong evidence that engineering can co-exist with liberal arts. However, we believe that it is still important to expose students to the big ideas of engineering in the vast majority of liberal arts school that do not, and are never likely to, have an engineering program.

The remainder of this report is organized as follows. In Section 2, we describe the *Robotic Design Studio* course that we have developed. In Section 3, we summarize how we have introduced robot-based activities into other classes in our curriculum. In Section 4, we discuss how we have disseminated the results of our curriculum development beyond the bounds of Wellesley College. Appendix A contains a sample syllabus from our course and Appendix B contains descriptions of some of the projects that students have built in the course.

2. *Robotic Design Studio*

2.1 A Brief History

Robotic Design Studio has been taught the past four years (1996 through 1999) as an intensive twelve-day course during Wellesley's three-week long January "Wintersession". The course requires a substantial time investment on the part of the students; it meets 3 hours per day, 4 days a week, for 3 weeks, and students spend many more hours outside of class working on their projects. The course culminates in an exhibit that is open to the entire Wellesley community and is typically attended by 100 to 200 people. (See more on the exhibit below.)

In 1996 and 1997 the course was offered on a informal, non-credit basis. In spite of the fact that the course offered no academic credit and required a substantial amount of time, a total of 20 students took the course during these first two years. In 1998 and 1999, *Robotic Design Studio* was offered for academic credit (it counts for half the credit received for a typical semester-long Wellesley course) and the course was oversubscribed. Each of these years about 40 students signed up, but enrollments were capped at 30 and 20, respectively. Tables 1 and 2 summarize the distribution of the students by year and department

Year	*'96*	*'97*	*'98*	*'99*	*Total*
First-Year	1	2	7	3	13
Sophomore	7		9	8	24
Junior	3	4	5	3	15
Senior	2		5	3	10
Other		1	2	1	4
Total	13	7	28	18	66

Table 1: Number of students in each *Robotic Design Studio* class, by academic year.

Department	*'96*	*'97*	*'98*	*'99*	*Total*
Africana Studies		1			1
American Studies			1		1
Anthropology	1				1
Art:		1	2	3	6
Biology:	2		6	1	9
Biochemistry			1	2	3
Chemistry:	1		1	1	3
Chinese:			1		1
Cognitive Science	2	1		1	4
Comp Science	4	3	10	1	18
Economics:	1		6		7
English:			4	1	5
French				1	1
Geology				1	1
History				1	1
International Relations			1	1	2
Latin American Studies				1	1
Math	2	2	5	3	12
Philosophy	1	1			2
Physics:	2	1	4	6	13
Political Science			1		1
Psychology	1		3	1	1
Russian				1	1
Sociology				1	1
Spanish			1		1
Theater Studies			1	1	2
Total	17	10	48	28	103

Table 2: Number of students in each *Robotic Design Studio* class, by department.

Note: Numbers do not add up to those in Table 1 because many students are double majors or listed their minor in addition to their major

2.2 Technology

2.2.1 Hardware

For building their robots, students had access to an extensive “computationally enhanced” construction kit that consisted of a rich assortment of LEGO mechanical and structural elements, motors and other actuators, various sensors, and also a number of different kinds of “programmable bricks”. These programmable bricks, which were developed at the MIT Media Lab, are tiny, portable computers capable of interacting with the physical world through sensors and motors. The programmable brick extends the student's construction kit, enabling them to build not only structures and mechanisms, but also behaviors. With programmable bricks, students can spread computation throughout their worlds, using programmable bricks to build autonomous robots and "creatures". By engaging students in new types of design activities, the programmable brick encourages students to see themselves as designers and inventors. At the same time, these activities can help students develop a deeper understanding of important scientific concepts related to behavior, feedback, and control.

We primarily made use of two different versions of programmable bricks, the palm-sized Handy Board, which is available commercially, and a new generation of programmable bricks called “Crickets”, which are part of a NSF-funded Media Lab research project for which one of us (RB) is a co-principal investigator. Crickets are smaller, lighter, and cheaper than their predecessors, and they have enhanced communications capabilities. In early versions of the *Robotic Design Studio* course, there were very few Crickets, and almost all projects were based solely on Handy Boards. Now we have about equal numbers of Crickets and Handy Boards, and projects are shifting more to Crickets or combinations of Handy Boards and Crickets.

It is worth noting that the commercially successful Mindstorms (RCX) product introduced last year by LEGO was inspired by the programmable prick work at the Media Lab. The availability of this product will greatly facilitate the adoption at other schools the kind of robotic design activities that we have developed for our *Robotic Design Studio* course.

Although they are not "hardware" in the traditional sense, we have found that art and craft materials for decorating robots are an essential elements of the construction kits. They dramatically increase the opportunities for the robot projects to have strong narrative and aesthetic components.

2.2.2 Software

In theory, any general purpose programming language could be used to program a programmable brick as long as it is extended with primitives for (1) reading input from brick's sensors (analog and digital sensor ports, infrared receiver, serial line); and (2) controlling the brick's actuators (motor ports, LCD display, beeper, infrared transmitter, serial line). It is also important to have some form of concurrency (in the form of simple process creation and destruction) in order to express independent and loosely coupled behaviors in a modular way.

In practice, there are only two language implementations that currently target the Handy Boards and Crickets.

1. ***Handy Logo*** & ***Cricket Logo*** These are subsets of the Logo programming extended with the input, output, and concurrency primitives mentioned above.

2. ***Interactive C (IC)*** This is a subset of the C language extended with the input, output, and concurrency primitives mentioned above. IC has several advantages over traditional C: its type checking is better and IC statements are executed via an interpreter. IC only exists for the Handy Board; there is no version of IC for Crickets.

In the *Robotic Design Studio* course, we have exclusively used Handy/Cricket Logo. A key advantage of these languages is that their syntax is very easy to learn (it was designed to be learned by grade school children), which lowers the barrier for first-time programmers (of which there are generally several in our classes). In contrast, the syntax of IC is much less intuitive and involves concepts (such as type declarations) that are simply absent in Handy/Cricket Logo. Another practical consideration is that there is only one language available for Crickets (Cricket Logo), which is almost identical to Handy Logo. It makes little sense for students to learn a very different language (IC) for controlling Handy Boards when two very similar languages suffice for the two kinds of programmable bricks.

A key technical difference between Handy/Cricket Logo and IC is data structure support. Handy Logo has only one datatype (16-bit integers) and its only "data structure" is a single global 8K array of 16-bit integers. In contrast, IC supports multiple datatypes (16- and 32-bit integers; single-precision floating-point numbers, characters) and for data structures supports pointers and both global and stack-allocated arrays. In the *Robotic Design Studio* class, students have never indicated that they have been held back by the lack of data structures in Handy Logo. In fact, most robot control programs in the project tend to be very simple. This is mostly likely because the two weeks (at most) students have to work on their projects is not enough time to design an elaborate controller in addition to completing the other aspects of the project. We conjecture that students with more time and more programming background might find good reasons to use the data structures facilities of IC, but as of yet, no demand has emerged for them.

The greatest disadvantage of Handy/Cricket Logo is that their implementation is proprietary software developed by the Epistemology and Learning Group (ELG) of the MIT Media Lab based on funding from LEGO. (In contrast, IC is freeware.) Consequently, we had to get special permission from ELG and LEGO to use these languages in our course as well as various workshops. We got permission to distribute Handy Logo to the four schools that participated in the Colby workshop that we led (see Section 4). It worth noting that the subset of these schools that have developed similar courses have opted to used IC instead of Handy Logo. This may be due in part to the fact that these schools teach C elsewhere in the undergraduate computer science curriculum, whereas Wellesley does not. Another important factor is that Crickets are still in the development stage and few schools have access to them; so other schools do not have to deal with the possibility of teaching IC for Handy Boards and Cricket Logo for Crickets.

In the final analysis, we are happy with our choice of Handy/Cricket Logo for the *Robotic Design Studio* course because we feel it has made the programming aspects of the course more accessible to students without a programming background. However, the proprietary nature of the software (and the Cricket hardware) is unfortunate, because it limits our ability to share aspects of our course materials with others.

2.3 Course Structure

Appendix A contains a revised syllabus from the 1999 *Robotic Design Studio* course. Here we focus on a few highlights:

2.3.1 Challenges

The first half of the course introduces students to the fundamentals of robot design through a series of lectures, handouts, and hands-on challenges. The Handy Board, sensors, actuators, and robot programming are introduced in the context of a fleet of so-called SciBorg robots. Experience has taught us that mechanical issues are problematic for novices, so it helps to get them started with already assembled robots whose mechanical designs have already been ironed out. Students first analyze the line-following behavior of SciBorg, and then modify SciBorg's program to implement other behaviors. Robot mechanics begins with a day on LEGO building cliches which culminates in a challenge of building a box containing a weight that can withstand a six foot drop. Another day is spent on gearing issues – a common stumbling block for many students. The associated challenge is to build a weight-carrying vehicle that will be raced against other vehicles. This challenge is spread out over several days to that students have a chance to iterate their designs. Finally, students explore Crickets, the sensor repertoire, and advanced programming features in the remaining challenges.

2.3.2 Design Project

The second half of the course is devoted to the robot design project, in which students work (usually in a team of two or three people, but occasionally on their own) to design, build, exhibit, and document a robot. This design project is really the focus of the student's efforts in the course. The project is open-ended, giving students a great deal of freedom in selecting a project that connects with their interests. This structure helps support our goal of having the course attract students with a wide ranges of backgrounds and preparations. When forming teams for a project, students are encouraged to choose teammates with complementary strengths. For example, it's good to have members with programming experience, mechanical know-how, artistic sense, and good writing and presentation skills.

As part of their robot project, students are expected to do the following:

As a group:

• *Develop* a preliminary design for their robot, including sketches and descriptions of behavior.
• *Build* the robot they have designed. This is an iterative process in which students build, program, test, see what works and what doesn't, and make changes to the design.
• *Document* their robot with pictures, text, and code in a World-Wide Web page that will forever remain a part of the *Robotic Design Studio* electronic museum.
• *Exhibit* the robot you have built at the Robot Exhibition on the last day of the course.

As individuals:

• *Document* the design and implementation of the robot in a design journal.

A collection of sample projects from the course are shown in Appendix B. It is striking to us that while very diverse in many ways, most of these projects possess a very strong narrative element.

2.3.3 Exhibition

A critical element in the organization of the *Robotic Design Studio* course is that it culminates in an *exhibition* rather than a *competition*.

Our *Robot Design Competition* course was in good measure inspired by MIT's "6.270" *Autonomous Robot Design Competition* course. In 6.270, students build robots to compete in a tournament style contest in which robots play a table top

60 second game against one another, with winners advancing to the next round. While this competition is exciting and motivational for many students (particularly the winners) we believe that by having our students focus on an exhibition we are able to create an environment that is more welcoming to novices and allows room for a greater range of creative expression, while still maintaining the motivational benefits of a public display of the projects.

2.3.4 Students as Teachers

One of the exciting aspects of this kind of course is that much of the "teaching" that goes on is between students. Students bring different areas of expertise to the course (*e.g.* programming, mechanical design, artistic design) and we have structured the course so as to encourage and facilitate students teaching one another. The work area is kept open 24 hours a day, and students spend a lot of time working on their projects when the professors are not in the room. Several alums from the course have returned in subsequent years to serve as teaching assistants.

We have seen a definite upward trend in the quality of projects from year to year, as the college community's collective knowledge of how to build these robots grows and is passed on. Also, as the Exhibition has developed into a campus-wide tradition with high visibility, students who come to view the projects one year gain inspiration for projects they can build when they enroll in the course the next year. Recently we have put a number of the best robot projects on display in a glass case in a public area of the Wellesley Science Center, so that students can receive year-round inspiration.

3. Robots Elsewhere in the Curriculum

In addition to developing the *Robotic Design Studio* course, we have begun to experiment with using robots in other physics and computer science courses. Thus far we have used robots in two courses and have plans to use them in more.

3.1 Electronics Course (Physics 219 - *The Art of Electronics*)

This laboratory course, taught by Prof. Berg, emphasizes construction of both analog and digital electronic circuits. It is intended for students in all of the natural sciences and computer science. The approach is practical, aimed at allowing experimental scientists to understand the electronics encountered in their research. Topics include diodes, transistor amplifiers, op amps, and digital electronics including microprocessors and microcontrollers and assembly language programming. The approach is similar to the one employed in the Horowitz and Hayes Student Manual, which was developed for the electronics course at Harvard. But this book is now 10 years old, and given the rapidly changing nature of electronics (particularly on the digital side) we have made significant changes over the years. Most notably we have added a substantial sections on microcontrollers and on robotics. We have also added a design project to the course: students design a circuit for a new "robot sensor" on their own, debug it on a breadboard and then use layout software to design a printed circuit board. The boards are sent out for manufacturing, but assembled and tested by the students. The sensors are designed so that they are compatible with the Handy Board and Crickets. Students then build a simple robot to demonstrate the use of their sensor. The use of the robot materials to contextualize the circuit design has noticeably helped motivate these circuit design projects; students feel a strong sense of empowerment when they realize they have the skills to do something like this.

3.2 Introductory Programming (CS111: *Introduction to Programming and Problem Solving*):

During Spring 1998, Prof. Turbak used the robots for one lecture and one laboratory of the introductory CS course for majors. The lecture (the 20th out of 26) introduced the Handy Board and the Handy Logo language. The theme of the lecture was that most of the ideas that the students had learned about programming in Java carried over to a programming language with a very different syntax and based on a different programming paradigm (imperative rather than object oriented). The laboratory (the 11th out of 13) had students work in groups on SciBorg robot challenges like those used in the *Robotic Design Studio* course -- e.g., analyzing the line-following behavior of SciBorg and modifying the robots to exhibit other interesting behaviors. The students caught on quickly, and a surprising number of teams were able to successfully analyze the line-following behavior and also solve all four behavior-modifying challenges within the two-hour laboratory time. Judging from the high-level of student interest and their performance in the laboratory, the robot lecture and lab were a success. It is likely that they will be kept in future incarnations of CS111.

3.3 Plans to Incorporate Robots into Other Courses

We also have plans to experiment with robot-based activities in other courses:

- *Introductory Mechanics:* As we have seen in the *Robotic Design Studio* course, robots are a compelling way to motivate many issues in mechanics, such as friction and torque. It is easy to imagine including robot-based activities in a mechanics course.

- *Programming Languages:* Prof. Turbak plans to use the robots in a programming languages course to illustrate issues in concurrent programming. Both the Handy Logo and IC languages support concurrency in the form of simple primitives for creating and destroying processes. They do not support any special communication primitives, so information exchanged between processes must be passed through global variables. The problems of such an approach will motivate the discussion of various communication and synchronization primitives.

- *Compiler Design:* The Handy Board is an intriguing target architecture for a compiler. Unlike most modern computers, where the hardware is hidden and operating systems perform significant "magic" behind the scenes, the Handy Board is an obvious piece of hardware with a simple operating system. These features may be pedagogically helpful in the context of teaching compiler design. Prof. Turbak plans to explore the use of Handy Boards in a compiler course.

- *Hardware Architecture and Operating Systems:* The Handy Boards are an excellent vehicle for experimenting with assembly-level programming and understanding machine architecture and operating systems -- compelling reasons to use them in hardware architecture and operating systems courses. However, the content and lab structure of these courses are currently well-established, and are not likely to change in the near future.

4. Dissemination

In a curriculum development project, we believe that it is important not only to innovate within the college, but to influence courses taught at other colleges by presenting and sharing the course materials with the rest of the world. We have employed two key means of dissemination: workshops and a website.

4.1 Workshops

During the past two years, we have led four hands-on workshops introducing both students and teachers to the robot technology and pedagogy we use in the *Robotic Design Studio* course:

- Colby College (October 24-25, 1997): Two-day NECUSE-sponsored workshop attended by 14 faculty members and 5 students from Bates, Bowdoin, Colby, and Middlebury colleges. Teams from participating colleges were supplied with two robot kits (paid for by NECUSE) to bring back with them to their home institutions.

- University of Hartford (March 24, 1998): One-hour workshop with computer science majors.

- Loomis Chaffee (private high school in Windsor Locks, CT, March 24, 1998): Two-hour workshop with students.

- Consortium for Computing in Small Colleges Third Annual Northeastern Conference (CCSCNE-98, Sacred Heart University, Fairfield, CT, April 24, 1998): Three hour workshop with twenty faculty and students from colleges in the Northeastern U.S.

These workshops have inspired a number of robot projects, including:

- During January 1999, Profs, Matthew Dickerson and Tim Huang of Middlebury College started to teach a January term robotics course that is modeled after the Wellesley *Robotic Design Studio* course. Additionally, Prof. Dickerson is planning to use the Handy Board robots in his introductory CS course for non-majors and Prof. Amy Briggs will be using them in her robotics course.

- This semester (Spring 1999), Prof. David Garnick at Bowdoin College has started to use Handy Board-based robots in his parallel computing course. He also plans to experiment with them in his CS1 course next year, and is seeking funding to create a web-based resource for undergraduate robotics projects.

- Profs. Batya Friedman, Allen Downey, and Clare Congdon at Colby College have received NSF AIRE funding to develop a robotics course similar to *Robotic Design Studio*. Michael Corr, a Colby student who participated in our workshop, became interested in robot programming languages and did an independent study in this area.

- Physics student Kristen Frederick at Bates College is using a Handy Board introduced during the Colby workshop in an independent project.

- Under the supervision of Prof. Elizabeth Adams (a participant in the CCSCNE-98 workshop), student Christopher Peery at the Richard Stockton College of New Jersey is undertaking an independent study project in robotics based on the Handy Board.

- Under the supervision of teacher Richard Goldschmidt, several students at the Loomis Chaffee school went on to assemble a Handy Board for use in robotics projects.

4.2 World-Wide Web Site

We have developed a website at

`http://www.wellesley.edu/Physics/robots/studio.html`

that disseminates *Robotic Design Studio* materials not only to students in the course but to the world at large. The following materials are published on the web site:

- All written materials developed for and/or used in the *Robotic Design Studio* course (in PDF format).

- An on-line "museum" of all the robot projects that students have developed for the *Robotic Design Studio* course. We made simple web pages (with pictures and descriptive text) for the projects from the two pilot versions of the course. One of the requirements for the credit version of the course is that teams publish a web document describing their robot project, including pictures, descriptive text, and code. An upshot is that the project web pages from the two credit versions of the course are more informative, artistic, and elaborate than those for the earlier projects.

- Photo albums of some exhibitions and workshops.

- Links to other robotics web-sites relevant to the course, particularly the Handy Board and Cricket sites at the MIT Media Lab.

Although we have no way to gauge the popularity of our site, we do know that it is linked from several other robot sites and is on the "favorite links" list of several robot builders.

4.3 Other Means of Dissemination

We are currently exploring several other opportunities for dissemination:

4.3.1 Journal Paper

We are currently working on an article for the Journal of Science Education and Technology that is based on our experience with *Robotic Design Studio* course. The focus of the article is on the importance of including the "big ideas" of engineering in a liberal arts curriculum. We will illustrate how such ideas arise in the context of the *Robotic Design Studio* course.

4.3.2 Additional Exhibitions/Workshops

It is likely that we will continue to hold various exhibitions and workshops outside of Wellesley College. For example, we have been invited to present a talk and exhibit at the "MindFest" conference and exhibition sponsored by the MIT Media Lab, to be held at MIT in Fall, 1999. We are also exploring the possibility of a collaborative workshop in conjunction with Professors Deepak Kumar (Bryn Mawr) and Lisa Meeden (Swarthmore).

Appendix A: Sample Syllabus

Wellesley College CS115/PHYS115
Robotic Design Studio
January , 1999

COURSE INFORMATION

Instructors: Robbie Berg (Physics), SCI554, x3110, `rberg@wellesley.edu`
Franklyn Turbak (Computer Science), `fturbak@wellesley.edu`
(Franklyn is on leave this year, but he will be helping out during the first week or so of the course.)

Location: SCI 396. (SCI 392 is also available as a work space.)

Meeting Times: 1pm -- 4pm, Monday -- Thursday, January 4 -- 25. There is no meeting on Martin Luther King day (Monday, January 18). All members of the class are expected to participate in the Robot Exhibition from 4:30 -- 6pm on Monday, January 25 and the cleanup party immediately following (6pm -- 7:30pm).

Course Web Sites: We maintain a web site for Robotic Design Studio, containing general information about the course, pictures from past years, *etc*. at:

`http://www.wellesley.edu/Physics/robots/studio.html`

There is also a web site with information pertaining specifically to this year's version of the course at:

`http://nike.wellesley.edu/~rds/`

For example, information about creating a web page for your robot can be found at this site.

Course Overview

In this intensive introductory course, you will have an opportunity to design and assemble robots out of LEGO parts, sensors, motors, and Handy Boards (palm-sized computers), and then program your creations to do your bidding. We start by learning some fundamental robotics skills in the context of studying and modifying a simple robot known as SciBorg. Then, working in small teams, you will design and build your own robot. The course culminates in a Robot Exhibition on January 25, from 4:30 -- 6pm, in which you will show off your robots to the Wellesley community. This is a festive event that is attended by students, faculty, staff, and their families.

This course is rooted in *constructionism*, whose main tenet is that people learn best when actively engaged in hands-on projects that are personally meaningful and enjoyable.

Robotic projects tie together aspects of a surprisingly wide range of disciplines, including computer science, physics, math, biology, psychology, engineering, and art. Here are some of the concepts and skills you can expect to learn in this course:

• Robot = sensors + controller + actuators
• Simple programming: robot commands, control flow (sequencing, conditionals, loops, procedure calls, concurrency), procedural abstraction
• Basic electronics: voltage, current, power, motors, sensors
• Fundamental mechanics: building robust structures, friction, power transmission, gearing, LEGO design clichés
• Animal and machine behavior, with ties to biological, cognitive, and social science.

More generally, by working on this design project you will also be introduced to some of the "Big Ideas" of engineering:

• hypothesis testing and debugging
• making iterative improvements
• working with *systems* , design in multiple domains, subpart interaction
• designing *behaviors*; sophisticated behaviors can arise from relatively simple rules
• working in the real (noisy, messy, unpredictable *etc.*) world
• divide-and-conquer strategies for problem solving
• modularity and abstraction
• feedback and control
• paying attention to *aesthetics*,
• the value of simplicity and robustness

We believe that it is critical that this kind of exposure to the important ideas of engineering be a part of today's liberal arts education; a grounding in these ideas is necessary in order to understand our times and our culture. The best way to become fluent with these ideas is to become a designer and a builder. In today's liberal arts curriculum there is a relative absence of design and building for students of science or technology. (In contrast, there tend to be lots of design experiences for artists and humanities students.)

Prerequisites

The only prerequisite for this course is a willingness to learn about, and have fun with, robots. The course is not just for scientists --- all creative people are encouraged to participate!

Credit

One-half (0.5) units of credit will be awarded for successful completion of this course. This credit counts toward the Natural and Physical Sciences (NPS) distribution.

Reading Materials

We will hand out several articles, manuals, and notes during the course, and will post suggested reading where appropriate.

Homework

In addition to design challenges and other hands-on activities in during class time, you will be asked to complete several homework assignments. Assignments will typically involve reflecting and expanding on work done in class, thinking about points raised in reading, or documenting stages in the design and construction of your robot.

Individual Design Journal

Each student is required to maintain an individual design journal to document her journey through the course. The design journal is a single artifact that should contain all of the following:

• Lecture notes taking during class.
• Answers to homework assignments.
• Documentation of your solutions to the design challenges, including sketches, code, and explanation of strategies.
• Documentation detailing the design and construction of your final project, including words, sketches, and code.
• Other thoughts/observations/sketches inspired by the hands-on activities, reading, *etc*.

We encourage you use a bound notebook such as a composition notebook or a spiral notebook for your design journal. We recommend that you do **not** use a loose-leaf binder for your design notebook. You should date each entry to the journal, and tape or glue loose materials (such as code listings) to pages in the journal.

Group Robot Project

The second half of the course is devoted to the robot project, in which you will work in a team of two or three people to design, build, exhibit, and document a robot. The project is open-ended; you should brainstorm with your teammates about projects that are fun, exciting, and challenging, but at the same time realistic. To give you a sense of what's possible, you should browse the following web pages:

`http://www.wellesley.edu/Physics/robots/web-pages-98.html`
(Descriptions of the 1998 robot projects.)

`http://www.wellesley.edu/Physics/robots/gallery.html`
(Descriptions of the 1996-7 robot projects.)

When forming teams for your project, it is wise to choose teammates with complementary strengths. For example, it's good to have members with programming experience, mechanical know-how, artistic sense, and good writing and presentation skills.

As part of your robot project, you will be expected to do the following:

As a group:

• *Develop* a preliminary design for your robot, including sketches and descriptions of behavior.
• *Build* the robot you have designed. This is an iterative process in which you will build, program, test, see what works and what doesn't, and make changes to the design. You repeat this process until you are done (rare) or you run out of time (more likely).
• *Document* your robot with pictures, text, and code in a World-Wide Web page that will forever remain a part of the Robotic Design Studio electronic museum.
• *Exhibit* the robot you have built at the Robot Exhibition on January 25, 1999.

As an individual:

• *Document* the design and implementation of the robot in your design journal.

Grades

Rather than focusing on a grade, we hope that you will focus on learning a lot and having fun while building creative robots. After all, students during two previous WinterSessions (‘96 and ‘97) built *very* impressive projects without receiving any credit at all!

Your grade for the course will be determined by three factors:

1. Your design journal, which includes your homework assignments and your individual documentation for your group final project.

2. Your group robot project, particularly the web page documenting your robot.

3. Your class preparedness and participation. It is expected that you will attend all classes (although we understand that travel plans may prevent some students from attending the first day of class).

Grading will be fairly lenient; conscientious participation in the course is likely to earn a grade between an A and a B.

Collaboration Policy

We strongly encourage you to get to know all of your classmates and to collaborate extensively with them. Because of the interdisciplinary nature of the course, it is likely that you will be strong in some areas but weak in others. Please share your strengths with others, and don't hesitate to ask others for help in the areas in which you feel that you are weak.

In your design journal, all observations, reflections, and documentation should be in your own words. You may reference the ideas of your classmates, but should give them proper attribution in your writing.

Laboratory and Computing Environment

Classes will be held in Science Center room 396 and the adjoining room 392. These will collectively be referred to as the "WinterSession Robotics Laboratory". In addition to class times, we will try to keep the labs open at other times to encourage playing with the robots and working on your projects.

The lab is equipped with 10 Gateway PC computers. If you have a PC laptop you can use it for this class if you like. We will primarily use three software applications during the course:

• Handy Logo and Cricket Logo -- program development environments for the Handy Boards and Crickets
• Claris Home Page -- a web-page builder
• Winsock-FTP -- a file transfer program for uploading files to and downloading files from the net.

Each student will be given a computer account on the Nike file server where **she should store her personal work at the end of each class day.** Details on accessing Nike via

Winsock-FTP will be provided. Students are also encouraged to make backups of their work onto floppy disks.

Course Schedule

There are twelve three-hour class meetings, which naturally split into two categories:

1. During the first six class meetings, we will teach you the basics of robot design. These meetings will consist of brief lectures interleaved with numerous hands-on activities in which you will modify an existing robot or build a simple robot from scratch.

2. During the last six class meetings, you will work with your teammates on the design and implementation of your robot.

Below is a tentative schedule for the class:

Monday, January 4 (Class 1) ***Introduction to Robotic Design***
- What is a robot? Sensors, actuators, and controllers.
- Introduction to the Handy Board, a palm-sized computer for robot controllers; executing simple commands and downloading programs.
- Course Administrivia
- Introduction to Handy Logo, a programming language for the Handy Board: actuator & sensor primitives; control flow (sequencing, conditionals, loops);

Build-Your-Own kinetic sculpture

Tuesday , January 5 (Class 2) ***Robot Programming***
More Handy Logo, procedural abstraction, level triggered vs. edge triggered, simple multitasking.
- Introduction to SciBorg, a pedagogical robot.
- Challenge: How does SciBorg follow a line?

Design challenges -- program SciBorg to do the following:
1) **Ping-Pong** "bounce" back and forth between walls using front and rear touch sensors
2) **escape:** escape from barricaded surroundings
3) **sobriety-test** - improve SciBorg line-following behavior by minimizing constant weaving on relatively straight portions of track.
4) **light follower** - get SciBorg to “home in” on a bright light source
- Saving work to Nike account.

Wednesday, January 6 (Class 3) ***LEGO Mechanical Design***
- Overview of LEGO Technic components
- Idioms for robust LEGO construction
- *Design challenge:* build a sturdy LEGO box that can survive a fall

Thursday, January 7 (Class 4) ***Iterative Design, Crickets***
- Power transmission: motors, gear trains, speed vs. torque trade-off, friction, worm gears, differential gears
- *Design challenge:* build a single motor racing vehicle. The vehicle will participate in a 3 meter race carrying the Handy Board and a1.0 kg mass.

Friday, January 8 (No Class)
- Although there is no class today, we will try to keep the lab open so that interested students can play. Watch for details.

Monday, **January 11 (Class 5)** ***Vehicle Races, Sensors***
- Testing and improving your designs, pre-race trials
- Introduction to the Cricket, Handy Board's smaller cousin.
- Cricket examples: dancing crickets, spider, scientific instrumentation
- *Design Challenge:* Communicating Crickets
- Gourmet snack

Tuesday, **January 12 (Class 6)** ***Advanced Robot Programming , Robot Project***
- Vehicle races
- Analog and digital sensors
  Standard sensor configuration; simple electronics
- Detailed description of how reflectance sensor works
- Demonstration of various sensors.
- Sensor Assignments:
  (1) find 10 different kinds of sensors in your environment (dorm, classrooms, science center, campus, *etc*.
  (2) find an interesting animal sensor and write a couple of paragraphs about what it's used for and how it works.
- **Robot project overview**. Show and tell: robots from previous years.
- Pick teammates for final project
- Groups begin brainstorming about robot project.

Inspirational Movies: Robo-pong, The Way Things Go, Cabaret Mechanical Theatre

Not done this year:
- Concurrency: launching processes, when demons, stopping processes, process families
- Design challenge: decomposing behaviors using concurrency.
- Revisiting earlier robot designs with concurrency in mind
- Shaft encoder/multitasking example

Wednesday, **January 13 (Class 7)** ***Design Session***
- Robot project brainstorming
- Work on preliminary robot project design: descriptions of behavior, sketches
- LEGO *Mindstorms* demonstration
- Video festival: *Robo-Pong*, *The Way Things Go* and more!

Thursday, **January 14 (Class 8)** ***Design Presentation***
- **Present preliminary design to class for feedback**.
- Begin implementation of robot projects.

Friday, **January 15 (No Class)**
- Although there is no class today, we will try to keep the lab open so that interested students can work on their robots. Watch for details.

Monday , **January 18** ***(No Class: MLK Birthday)***
- Although there is no class today, we will try to keep the lab open so that interested students can work on their robots. Watch for details.

Tuesday, January 19 (Class 9) ***Robot Implementation***
- Groups continue to implement and document robots.
- Tutorial on using Claris Home Page to create final project web pages.
- **Submit design journals for feedback on project**

Wednesday, January 20 (Class 10) ***Robot Implementation***

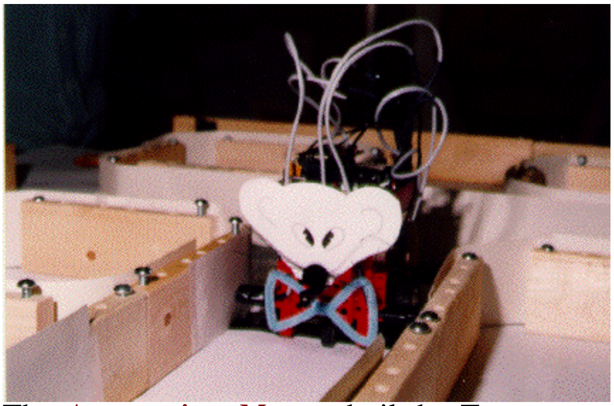
- Groups continue to implement and document robots.
- Tutorial on incorporating pictures and video into your robot project web pages.

Thursday, January 21 (Class 11) ***In-Class Exhibit***
- **Groups present working robots in preliminary in-class exhibit to get feedback.**
- Robot implementation and documentation continues.
- **Submit draft of web page for feedback**

Friday, January 22 (No Class)
- Although there is no class today, we will try to keep the lab open so that interested students can continue to work on and fine tune their robots. Watch for details.

Monday, January 25 (Class 12)
- Individual notebooks and group robot web pages due today.
- Testing robots in the exhibit space (Sage Lounge, 2nd floor of Science Center)
- Last-minute modifications to robots.
- **Robot Exhibition**: 4:30--6pm in the Sage Lounge.
- **Cleanup Party:** 6pm--7:30pm

Appendix B: Sample Projects



The ***A-maze-ing Mouse***, built by Tara Feinberg and Elena Konstantinova used reflectance sensors (to detect the walls) and a clever algorithm to navigate through a maze of arbitrary shape and find its way to a chocolate chip cookie.

The Catapulting Carpool, designed by Selena Burns, Janet Costello, and Alta Lee, is a crowd-pleasing favorite. It visits a series of LEGO castles, using reflectance sensors to follow black paths up to the castle walls. When its front bumper detects the wall, it plays a farewell song, dispenses a knight onto the catapult, and hurls the knight over the wall!

Coolosaurus Rex, a dinosaur robot built by Christina Chen and Kyung Yi, is a mechanical wonder. It features a high-stepping rhythmic gait that propels it along.

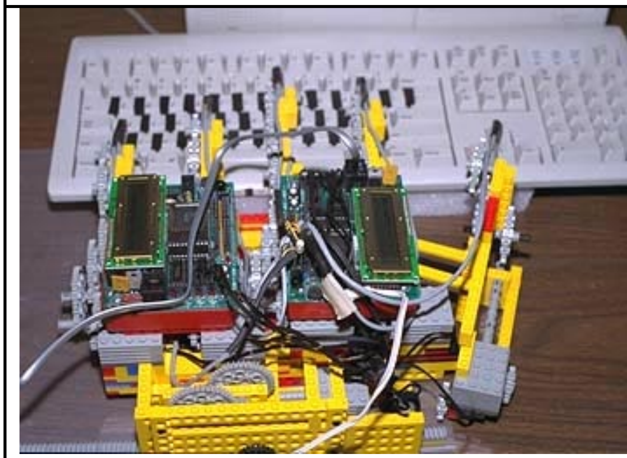
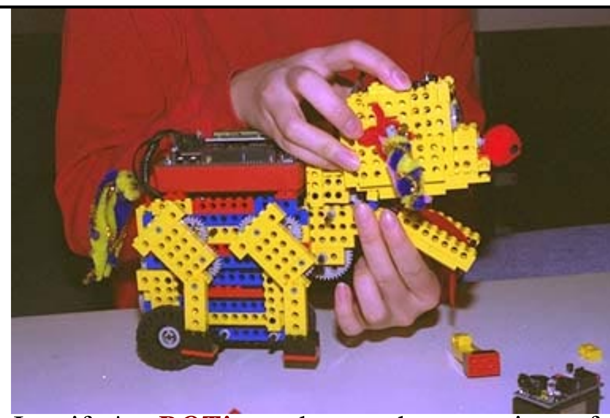
Leo the Artist, designed by Jill Foley, used a robotic arm to grab colored markers and draw wonderful pictures of flowers and trees as it moved over the canvas.

In ***Xylophone Player***, Becky Lippmann built an ingenious LEGO robot that could play a toy xylophone. The robot moved back and forth along a track, using a reflectance sensor to keep track of which key it was over. A spring-loaded arm held a mallet which could strike the keys with just the right touch. People could get the robot to play by moving along a huge paper keyboard taped to the floor. An ultrasonic position sensor detected the person's position, then relayed the information to the robot via an infra-red signal. Knowing where the person was standing, the robot then played the corresponding note!

Jennifer Gilchrist built ***Bumphries the Bombastic Bridge Layer***, a robot that spans a gap between two tables by laying down a bridge and then crossing over it!

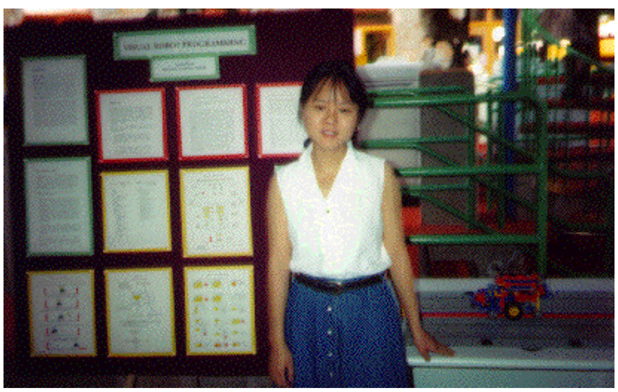
In ***Robot Tag***, by Caitlin Hall, Becky Lippmann, and Claudia Wagner two robots play tag. Each has light sensors that can detect the white light bulb on top of the other. The "hunter" (the robot that is "it", designated by a red light) chases the other robot, which tries to run away. If the two robots touch, they switch roles. If a robot hits a wall, it backs up, turns, and continues forward.

Inspired by her interest in competitive rowing, Becky Lippmann built ***Row-Bot*** , whose realistic rowing motion enabled it to paddle around a turtle shaped pond. The Row-Bot started moving whenever it heard a "clap". (It used a "clap sensor" that was designed and built by Laura Wollstadt.)

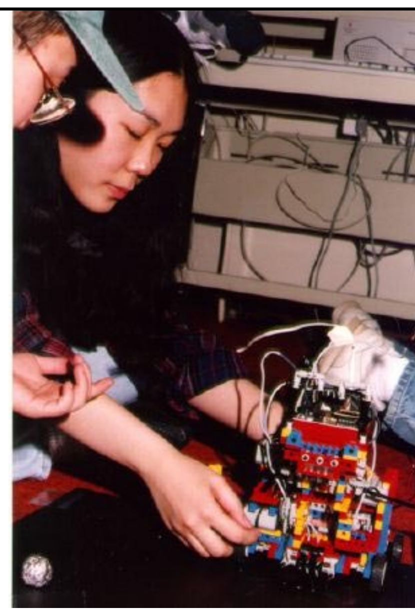
 In the ***Handroid*** project, Elena used two Handy Boards to control a six-motor LEGO hand that could type anything you want. The Handroid moved back and forth along a gear rack, and light sensors at the tips of each of its fingers counted keys as it moved.	 Tiina's ***The Chimera*** was an incredible display of artistry and mechanical ingenuity. Not only did the Chimera flap its wings, with a wonderfully life-like motion, but it also walked on eight paws, responded to your patting its head (purring) or pulling its tail (meowing).
 Natalie Douglas's ***Gigi in the Box*** is a roving jack-in-the-box, that "pops" when it bumps into something.	 Jennifer's ***sBOTina*** robot pet has a variety of behaviors, including walking, turning its tail, bobbing its nose, and opening and closing its mouth. sBOTina had a magnetic tongue, which would pick up steel "doggie biscuits".

Laura Wollstadt's ***Katy the Cockroach*** is a six-legged creature propelled by an interesting gearing mechanism.

Ruth Chuang '96 helped in the early development of the Robotic Design Studio course. She is shown here with her Venus Fly Trap robot. For her senior independent work, Ruth was involved with a project called 9 Techno Girls City . She worked with a group of 5th grade girls from the Hennigan School in Boston to build a "city of the future" out of LEGOs and Programmable Bricks.



Laura Diao's ***Follower*** uses reflectance sensors to follow your hand as you move it back and forth. It was designed for permanent use in one of the Science Center's display cases.



The Egg-Eating Praying Mantis, created by Connie Chang, Marie Hwang, and Masako Yamada, zig-zags forward until it detects (using reflectance sensors) a metallic egg in front of its mouth. Closing its arms, the Mantis pushes the egg into its mouth and "swallows" it, then celebrates its meal by dancing to the tune of the Mexican Hat Dance.

Wintersession 1999

Robotic Design Studio

in association with

Anna Raphael, Emily Puente, and Laura Graff

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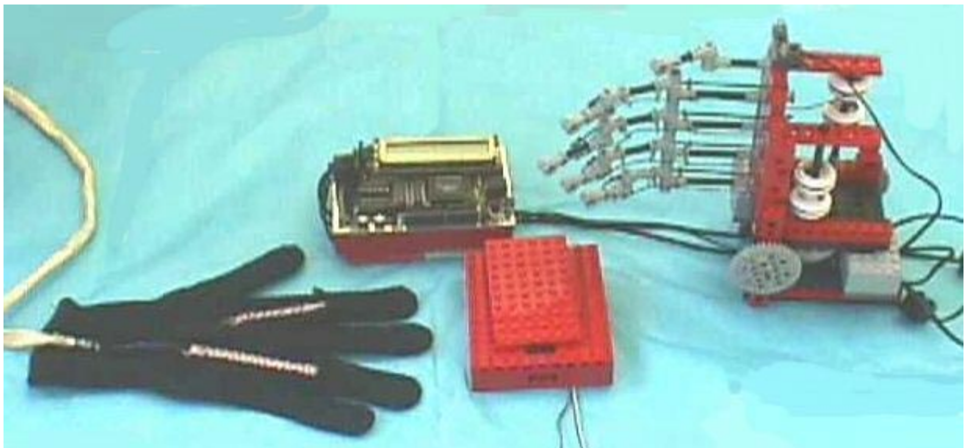
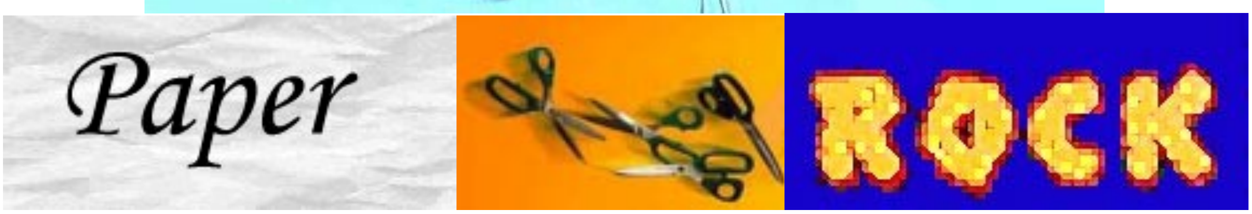




Paper-Scissors-Rock: let the game decide.

Paper-Scissors-Rock is a common children's game used mainly to determine who gets first pick, first possession, or the last fudgesicle. It's an alternative to flipping a coin. After a count such as "one, two, three, shoot" the two players throw out either a fist (rock), open hand (paper) or horizontal peace sign (scissors). Rock smashes scissors to win, but loses when covered by paper. Scissors cut paper (wins) but is crushed by rock. Paper beats rock but is vanquished by the snipping, snipping of the insidious scissors.

In ***Paper, Scissors, Rock*** , a robotic hand with four moveable fingers and a stationary thumb is capable of closing itself into a fist for rock, throwing out just two fingers for scissors or throwing out four fingers for paper. The robot randomly "decides" what to throw. The human opponent wears a glove equipped with sensors so that the robot "knows" what the human threw and can determine the winner. Human and robot play to determine the best of three games.

Lullabye and Good Night

designed by:

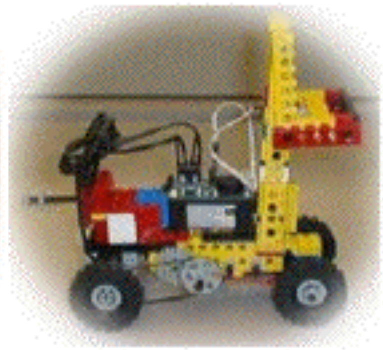
Andinet Amare & Desiree Urquhart

Lullabye and Good Night features Ms. Wendy Wellesley on a typical day as a "mum alum" while she attends to her Y2K bundle of joy born Mother Wendy has dismissed the trend to use mobiles and play-stations to entertain her toddler daughter and has opted instead to employ the "old school" of care for "Baby Wendy Wellesley" (BWW). Wendy and BWW spend countless hours at the computer, singing or enjoying poems by Robert Frost and Rita Dove. Mum has no doubt that BWW is well on her way to joining another generation of phenomenal Wellesley women in the red Class of 2020. Wendy is a jet-setter, mover and shaker in economics and international relations with a plethora of family, friends and business associates. She is married to Mike, an MIT physics geek. The sound of phones, faxes, "You've-Got-Mail" and doorbells are constant annoyances in their household. Wendy is a gourmet cook and is known for planning elegant soirees at the drop of a dime, but never at the expense of spending quality time with BWW.

In our design, BWW is used as the actuator to begin our robot's behavior. Upon a loud noise or clap, she cries and wiggles. Her head moves from side to side towards and away from the sensor we attached to her hand which is programmed to send an infrared signal from the cricket mounted on the headboard of the crib to turn on the motor for the wheel base of the mother operated by a cricket mounted on the breast feeder when the measured distance from the reflectance sensor on the doll's arm to the doll's face is equal to "1". Mother Wendy moves forward toward the crib. Her quick movement is made considerably slower and more gentle by reducing the default motor speed from 8 to 3.

When Mother Wendy's touch sensor comes in contact with the crib, "switch a" is turned on which then signals the breast feeder to move forward to deliver a bottle to BWW. While the breast feeder moves forward, it pushes the bottle along a platform until it reaches an opening large enough to allow the bottle to drop from Wendy's chest into the crib. The breast feeder retracts along the tracks and then Mother Wendy reverses direction as if convinced that BWW is satisfied.

Baby Wendy may or may not cry again but to be sure of being totally attentive, Mother Wendy returns to the crib to sing Brahms cradle song, "Lullabye and Goodnight" which BWW loves to hear.

mars & venus go robotic!

by Tate Burke

Right from the beginning, I knew that I wanted to build robots based upon animal behavior. This idea was inspired by the excellent documentary "Fast , Cheap, and Out of Control". The film presents the unusual occupations of 4 men, including a scientist at the MIT AI lab, whose robotic creatures display insect-like motion and attributes. Though I had visions of grandeur involving hordes of tiny Cricket robots which ran in packs and exhibited disturbing Hobbesian social behavior (see the link to "Development: or, Ideas Which Didn't Make It"), time and resources dictated that I scale down. For my final project, I set out to incorporate "mating rituals," "falling in love," and "reproducing," using 3 Crickets, 4 motors, 2 touch sensors, and 1 light sensor. The next step was choosing the species, since I wanted to make the robots recognizable and even anthropomorphic.

I decided to move up the evolutionary chain and use avian biology as my example. Though we used LEGO bricks to construct our robots, I ask you to suspend your disbelief and imagine feathers. Venus, the female, is large

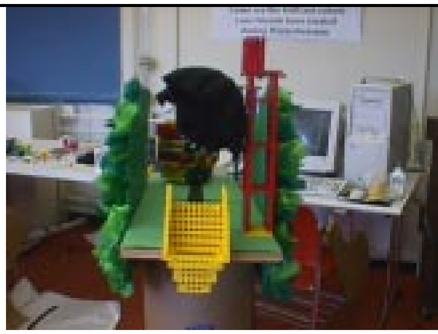
and drably colored, while her male counterpart, Mars, is brightly "plumed." Mars begins with a mating dance, and then croons a love song to Venus. He advances towards her and touches her. At his touch, she either a) rejects him, by accelerating away from him and beeping her disdain or b) falls in love, singing his song back to him, and releasing her trapdoor to give birth to Baby, who emerges and mimics his parents' love song. I hope to have some video clips soon, but in the meantime, you can check out the different aspects of their creation.

Squirrel Trap

by Allison Dupuy and Krista Miller

"Squirrel Trap," designed and created by Allison Dupuy and Krista Miller, was inspired by the video "The Way Things Go," a film by Peter Fischli and David Weiss.

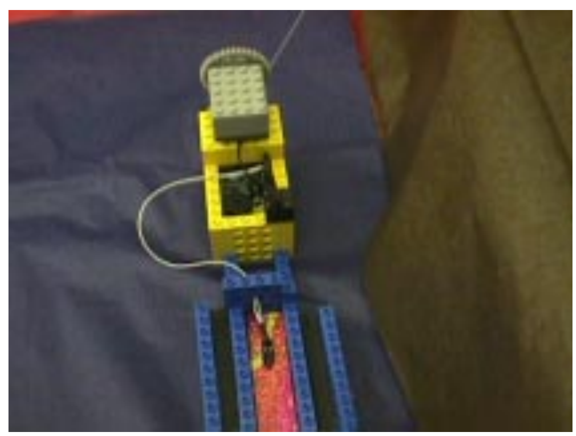
Basically, "Squirrel Trap" is a series of chain reactions triggered by a marble which serves as a model of an acorn. The entire series of chain reactions begins with the "evil, Wellesley squirrel" who sits perched on the tree. When the switch on the tail of the squirrel is activated, the squirrel begins to dance, sings a teasing song, and moves its tail up and down. Once the tail reaches the back of the squirrel, the edge of the tail hits a switch which triggers the squirrel to follow a black line through the tree.

 **1-** Once the squirrel hits the yellow funnel system at the end of the tree, the squirrel releases the marble.	 **2-** The marble then drops from the funnel system into a seat on the ferris wheel
 **3-** The added weight of the marble propels the ferris wheel to spin clockwise and release the marble into the marble maze.	 **4-** At the bottom of the marble maze, the marble drops into the mouth of the infamous "rabid skunk" which is powered by a Handy Board

5- The marble then falls through a tunnel system created inside of the robotic skunk. Once the marble passes by a distance sensor inside of the skunk's body, the skunk is triggered to move forward and follow a black line towards a barrier at the edge of the box.

6- Once the switch located below the tail of the skunk hits the barrier, the skunk opens a trap door at the edge of it's tail and releases the marble into the funnel system located at the top of the hoop. When the marble is dropped into the funnel, it triggers a switch which tells the Cricket located in a box at the top of the loop to send a signal to the other Cricket located in the "Wellesley" vehicle to move forward.

7- The forward movement of the vehicle causes the hoop to roll towards the ramp until the funnel hits another barrier where the marble is released into a cone



8- The marble then moves through the cone and out onto the ramp. At the bottom of the ramp there is a switch which is attached to another cricket

When the marble hits this switch, it triggers the motor attached to this cricket to turn on. When the motor turns on, the pulley system (9,10) is activated and the black trap (11) falls onto the squirrel's head, thus triggering the darkness sensor.

Once the darkness sensor is activated, the squirrel plays a song.
At last, we have trapped the "EVIL, WELLESLEY, SQUIRREL."
REVENGE TRULY IS SWEET!