Robotic Design Studio: Exploring the Big Ideas of Engineering In a Liberal Arts Environment (Extended Abstract)

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Abstract

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 small embedded computers. The course culminates in a robot exhibition where students show off 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 four years. A web site with detailed descriptions of student projects and all other course materials can be found at: `http://cs.wellesley.edu/rds.`

Introduction

Traditionally, engineering courses have had little or no place in a typical liberal arts curriculum. Engineering often gets put aside because it is too practice- and detailed-oriented, The purpose of liberal arts education is to give students the necessary set of intellectual tools to live fulfilled lives, not to give a narrow professional training.

> The purpose of the [liberal arts] college was partly defined in contradistinction to other forms of education: a [liberal arts] college education was supposed to be broad rather than specific, "liberal" rather than professional, relevant but not "narrowly vocational". *(Reuben 1996)*

This separation between engineering and a liberal education goes back a long way; the use of word "liberal" to describe this kind of education dates to the ancient Greeks. They conceived of the liberal arts as an education for "free men", namely those who had the luxury of pursuing ideas and thoughts without the burden of having to do something as mundane as making things.

Today, most people view engineering as a highly specialized set of disciplines, to be studied at the university level by a small handful of specialized technicians. But we see engineering much more broadly. Our aim is to change the image (and the reality) of engineering, transforming engineering into a subject that is learned (and enjoyed) by all liberal arts students. We do not expect (or want) many of our students to be professional engineers. But we feel it is important for engineering to be part of a liberal arts education because:

- At its core, engineering is about making things. Educational research based on constructionist theories of learning has shown that people's richest learning experiences often come when they are engaged in creating, designing, and making things (see, for example, (Papert 1994)). So by helping people learn how to make things, we also help them become better learners. And yet, in large part because of the absence of engineering, design-based learning is mostly absent from the liberal arts curriculum.

- There are many "big ideas" in engineering (*e.g.*, feedback, control, managing complexity) that are important for understanding not only classic "engineered systems" but also for understanding biological systems and social systems. So by learning about engineering, students gain a foundation for understanding many other disciplines as well.

- One result of a liberal education should be to allow students to understand and appreciate the modern world and to be able to make informed decisions about critical issues. In today's world we constantly interact with a vast array of often intimidating and mysterious technological objects. When students become designers and builders of technology, rather than passive consumers, much of the mystery and intimidation vanishes (Resnick, Berg, and Eisenberg 2000).

Motivated by these beliefs, we set out to design an introductory engineering experience at our home institution, Wellesley College, a undergraduate liberal arts college for women. In order to capture the essence of engineering, we wanted to engage our students in the hands-on process of constructing their own engineered artifacts rather than simply have them learn about engineering or study artifacts made by others. Inspired by the successful use of robot-based experiences in a variety of settings (*e.g.*, (Martin 1994), (Martin 2000), (Druin 2000), (McCartney 1996), and (Jones, Flynn, and Sieger 1998)) we decided to try to adapt this approach to a liberal arts college environment. The absence of a formal engineering program (or even much of a presence of engineering anywhere in our school's curriculum) makes this setting significantly different from most of the universities that have previously implemented robot building experiences. This led us to develop a course which is in some important ways quite different from courses developed elsewhere. We designed our course guided by the following criteria:

- Because we believe that all of today's liberally educated students should have an understanding of the big ideas of engineering, we designed our course to be accessible to all students, regardless of background.

- There should be multiple entry points in order to capture the interests of a diverse student body, many of whom do not initially consider themselves to be "interested in engineering".

Robotic Design Studio

In pursuit of these goals we developed *Robotic Design Studio*, an intensive laboratory course in which students are first introduced to the basics of robotics and then work in groups to design, implement, and exhibit their own robotic creations. In many ways the course has exceeded our wildest expectations. Our course has no prerequisites and over the last six years has been taken by over 125 students with a very wide range of backgrounds. 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.

For building their robots, students had access to an extensive "computationally enhanced" set of construction materials 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 (Resnick, et. al., 1996). 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".

We have employed two different kinds of programmable bricks: the palm-sized Handy Board, available commercially (see `http://www.handyboard.com`), and a new generation of smaller programmable bricks called Crickets (Mikhak, *et. al*., 2000), both of which were developed at the MIT Media Laboratory. 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.

The programming languages used in the *Robotic Design Studio* course are Handy Logo and Cricket Logo. These are subsets of the Logo programming language that were developed for the Handy Board and Cricket by Brian Silverman and others at the Media Lab. These versions of Logo have been extended with special primitives for obtaining sensor data and controlling actuators.

We have found that art and craft materials for decorating robots are essential elements of the construction materials students have access to. They dramatically increase the opportunities for the robot projects to have strong narrative and aesthetic components

Robotic Design Studio typically meets for twelve or thirteen four-hour sessions over a three and a half week period during the month of January. The first six or seven sessions are based around a series of challenges and focus mainly on programming, and mechanical and structural design. For example, as an introduction to working with programmable bricks, sensors, and motors we ask our students to build an interactive "kinetic sculpture". Several challenges involve a pre-constructed LEGO robot we call *SciBorg*. Students determine how SciBorg follows a line, and then program SciBorg to accomplish several other tasks. After they have learned idioms for making strong LEGO structures, the students must build an "indestructible box" that can survive a six-foot fall without breaking apart. There is also a gearing challenge that involves building a drag racer that can carry a one kilogram mass and a Handy Board, powered by a single low-torque LEGO motor.

During the second half of the course, the focus shifts to designing and building a robot from scratch. After a series of brainstorming sessions, students divide in groups of one, two or three members to work on their final projects. In these open-ended projects, students are encouraged to create any robot that interests them; they are limited only by their own imaginations and the available resources.

On the final day of the course, students present their robots to the community in a public exhibition. They also create a web page describing their robot that is added to an on-line museum of all projects. In addition to these artifacts, students keep a design journal to document their journey through the course. The design journal encourages the students to reflect on the process of engineering as well as the final product.

What's the Big Idea?

We should be clear what we mean when we say we want our students to learn the “big ideas of engineering.” We are *not* arguing for a standard professional engineering training that emphasizes the mastery of narrow, though perhaps very practical, skills (*e.g.* C++ programming or web page design). Rather we seek to expose students to broader engineering concepts and general principles, such as:

- **Design and implementation cycle:** The essence of engineering is imagining something, designing it, building it, and getting it to work. Robotics a rich and accessible domain in which to experience this process. Furthermore, in the course of their robotic projects, students learn that engineering is an iterative process in which they continually implement, test, debug, and refine designs. This process stands in stark contrast to many traditional experimental lab courses in the sciences, where students (unlike practicing scientists) rarely have a chance to design and iterate experiments.

- **Systems:** A key challenge of engineering is that it often involves the design of a complex system with interacting parts, many of which may be quite different in character (e.g. mechanical, electrical, computational, *etc*.) Robotics projects naturally involve design in multiple domains and provide a context in which to explore classic systems issues, such as feedback and control, and techniques for controlling complexity, such as modularity (composing systems out of reusable mix-and-match parts) and abstraction (capturing and generalizing idioms). These projects also provide students with an opportunity to observe emergent phenomena, such as complex behaviors arising from simple rules.

- **Designing in the real world:** Engineering is something that takes place in the world, not in a textbook. One of the most important lessons students learn from their robotics projects is that the real world tends to be much messier, noisier and more unpredictable than they expect from the idealized view that dominates textbooks and problem sets. Robotics projects also effectively highlight issues such as design trade-offs and managing limited resources.

Exhibitions, Not Competitions

A critical element in the organization of the *Robotic Design Studio* course is that it culminates in an *exhibition* rather than a *competition*. Our 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 competitions are exciting and motivational for many students (particularly the winners), we believe that an exhibition format is more welcoming to novices, attracts a broader range of students, and allows room for a greater range of creative expression, while still maintaining the motivational benefits of a public display of the projects. The exhibition is widely publicized, much like an art gallery opening might be, and is attended by about 250 people, including many children. The advantages to this approach include:

- **Personal expression:** Students experience a deep thrill in being able to start with nothing more than a vision and a “blank canvas” and end up with a tangible, almost living, expression of that vision. Our hope is to capture a feeling similar to that experienced by an artist and novelist when they create a work. Allowing students the freedom to work on a project of their own choosing increases the level of personal investment they feel in their project. This personal connection is, according to constructionist learning theory, a critical factor in creating an environment that is conducive to learning. Furthermore at the exhibition students receive the benefit of feedback on their work from a varied and appreciative audience.

- **With an exhibition, you can’t lose:** A core design principle is that we are trying to attract and be welcoming to novices. A competitive event is, for many novices, not very welcoming; the prospect of having to compete against a least some local experts in a public forum is daunting. Exhibitions provide an opportunity in which all participants can be successful.

- **Low floors, high ceilings:** While our course is an entry level experience for many, some students do come to it with a considerable amount of relevant experience. It is important to provide a suitable challenge for these more experienced students, and the open ended nature of the exhibition format allows this.

- **Addressing the gender gap:** We cannot help but notice that most robot competitions (as well as most engineering professions) are overwhelmingly male in composition. As we designed our course we were guided by the intuition that an exhibition format would be more likely to attract female participants compared to a competitive format. Of course, since Wellesley is an all women's college, we are not in a position to test this hypothesis. It would be interesting to see what gender mix would be found in a course like ours if it were offered in a co–educational environment.

It is worth mentioning that competitions have some advantages over exhibitions. Engineers rarely have the luxury of picking their own problems or having few constraints on the resources they use. In this respect, competitions better reflect the real world; robot contests typically involve solving a problem specified by someone else using a limited set of materials. Furthermore, when everyone is working on the same problem, they can gain a better appreciation for solutions developed by others.

We recognize these benefits, and also recognize that different students have different learning styles. For some students, a competition may be more motivating than an exhibition. We address this issue in *Robotic Design Studio* by presenting an option for our students to use our course to start building a robot to compete in the annual "Fire Fighting" contest held at Trinity College in Hartford, Connecticut (`http://www.trincoll.edu/events/robot/`).

Robots That Tell A Story

The ground rules governing the robots that our students build are intentionally kept extremely loose. We provide abundant resources and simply ask the students to build some sort of robot that they would like to show off at the final exhibition. Not surprisingly, over the years an incredibly wide range of projects has been presented. There have been all sorts of whimsical creatures and contraptions, such as a friendly smoke breathing dragon, a gorgeous six-foot-long car wash, a robot that can play "rock, paper scissors" with you, a robotic mother that comforts her crying baby with a bottle of milk, and a road-crossing, egg-laying chicken. There have been re-enactments of great scenes in literature and cinema, such as *The Wizard of Oz* , *Romeo and Juliet*, *The Tortoise and the Hare*, and the story of the Trojan Horse. Short of attending the exhibitions, the probably the best way to get a sense of this variety is to visit our online robot project museum at

`http://cs.wellesley.edu/rds/museum.html`,

which contains web pages made by each team of robot builders for their projects.

Looking at the robots built over the years, a few unmistakable themes emerge. There is a strong narrative element to many of the projects; students often use their robots to tell a story, and they enjoy telling stories about their robots. Students often build robots that reflect their interest in other disciplines and extracurricular activities. Finally, most projects manage to combine good engineering with artistic flair and dramatic expression.

These observations serve to underscore what a good match robotics is to a liberal arts culture, where people are encouraged to explore and find connections across a range of disciplines. It also suggests that the Greeks were wrong: engineering is a liberating activity that *should* be a component of a liberal arts education.

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