



Press Play: A Course in Interactive Device Design

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Abstract

Press Play: Interactive Device Design is a four-year-old introductory course at Stanford that explores the human-centered and technical workings behind interactive devices ranging from cell phones and video controllers to household appliances and smart cars. Students build a working MP3 player prototype of their own design using embedded microcontrollers, digital audio decoders, component sensors and other electronic hardware. Topics include electronics prototyping, interface prototyping, sensors and actuators, microcontroller development, multimodal displays, physical prototyping, user needs and usability testing.

The course is intended as a deep-dive introduction to electrical engineering through the vehicle of interactive device design. Students having a general familiarity with the products of electrical engineering engage with the underlying tools and technologies that make such products possible. By focusing the class project on the design of a digital music player, we aim to attract a broad demographic, and to illustrate how human-centered design considerations can be integrated into the system design process.

We present this course description—which encompasses motivation, implementation and assessment—to provide insights and inspiration for those looking to teach similar courses.

1 Introduction

Build a better music player—yourself! is how Interactive Device Design is advertised to students considering a concentration in engineering. The catchphrase captures two motivating principles of the course: first, that it is about *building* things, through hands-on lab and homework assignments and a final project; and second, that it involves making things *better*, by finding and then addressing a current product or interface design problem. In particular, the course strives to impart the skills and knowledge described in Table 1.

Desired Learning and Ability Outcomes	
a	Identify, formulate and express real-world, contemporary design engineering problems; in particular, from a user's perspective.
b	Apply the design and engineering skills, modern tools and techniques used by practicing engineers.
c	Gain familiarity and experience with properties of prototyping materials and fabrication techniques.
d	Design and build an electronics, software and hardware based system to address identified design problems, bound by constraints that include limited time, budget and personnel.
e	Effectively communicate complex design engineering issues, including the problem context, design approach and proposed solution, to both domain specialists and a broad population.

Table 1: Desired learning and ability outcomes for Interactive Device Design students, developed through hands-on lab and homework assignments and a final design project.

A digital music player makes for a particularly apt project, because it presents students with an interactive device that is at once familiar, yet at the same time, can become a challenge to use—safely, easily or as needed—over a breadth of everyday situations. We believe that this type of activity attracts a different sort of student than would be interested in say, a robot competition.

2 History

The quarter-long course has been offered seven times over the course of four years, in the spring and summer quarters of 2010 through 2013. Although the course was originally intended to encourage freshmen and sophomores to concentrate in electrical engineering, it has, in fact, attracted a wide range of students, from high school summer program freshmen looking for enrichment, to electrical engineers looking for more design training, to PhD and MD students looking to gain additional skills and discover technical tools (Table 2).

	Spr 2010	Spr 2011	Sum 2011	Spr 2012	Sum 2012	Spr 2013	Sum 2013
Freshman	0	2	13	1	13	1	29
Sophomore	1	3	0	3	0	10	0
Junior	4	2	0	6	2	6	0
Senior	5	11	0	7	0	7	0
Visiting	0	0	2	0	9	0	20
Graduate	3	0	4	3	6	8	4
Total	13	20	19	20	30	32	53

Table 2: Course enrollment over the last four years. During the summer, high school program students are listed as freshmen (their official status), while visiting undergraduate students (enrolled at another university, but attending for the term) are not broken out by academic year.

We have kept up with growth in enrollment thus far by recruiting additional student teaching assistants, and moving to larger electronics and physical prototyping labs.

The course makes significant use of contemporary trends in the do-it-yourself hardware community. Using commercially available microcontrollers and breakout boards as platforms, leveraging shared code and online tutorials as course materials, and sourcing components from hobbyist vendors such as Sparkfun and Adafruit extends the range of resources available for students to work with on their projects. Far from discouraging online research, we ask students to search online for inspiration and guidance as their first step, give proper credit to original authors, and give back to the community by posting instructions and videos for others interested in building upon their work.

3 Structure and Approach

Interactive Device Design is organized into four threads, woven together, and intended to complement and support each other: lectures, lab and homework assignments, and a design project.

Lectures: Coupling Design and Engineering

Lectures alternatively focus on a design method or practical technical topic. In doing so, we intend to convey the tight coupling between design and engineering concepts and action in conceiving, implementing and evaluating digital-physical products. The design oriented sessions at first introduce students to product design fundamentals, including an introduction to users, needs and point-of-view;^{4,11} affordances, which are the ways that products reveal their functions to users;^{6,9} and design principles, such as visibility, feedback and mapping.^{7,10} These few topics, in particular, provide students with the vocabulary they will need to work as, and with, experienced designers in their academic and professional careers. Toward the middle of the term, as students transition from completing lab and homework assignments to conceiving and prototyping their own projects, lecture topics shift to implementation, including usability, the ease of use and learnability of a product or its interface;⁸ interaction design, a product's physical, digital, behavioral and social considerations;¹³ and hacking and prototyping, including the history and resources available through the do-it-yourself community.³

The technical sessions introduce students to the programming, circuit-building and fabrication knowledge that they will need to complete labs and design projects. As such, the earlier sessions focus on power and sensor circuits,^{5,12} microcontroller architecture² and firmware programming.^{5,12,14} Again, toward the middle of the term, as students begin their design projects, we introduce digital communication, device enclosure fabrication and short-run printed circuit board manufacture. Toward the end of the term, the founders of music streaming and consumer electronics companies guest lecture, to help students to contextualize how what they are learning is used in industry and beyond. Taken together, the design, technical and guest lectures encourage students to internalize a self sufficient, hack-something-open, find-the-answers-on-your-own, engage-the-community, attitude.

Labs: Developing Practical Hands-On Engineering Skills

The challenge in designing lab and homework assignments is to get students out of their chairs, out of the building, to engage users, work with their hands, and develop practical design engineering skills. Our approach was to develop more intensive labs that focus on engineering, and lighter-weight homework assignments that focus on design.

The lab sequence is designed to develop students' electronics know-how and capability through the building of a series of complete, functional devices (Table 3). While each lab builds upon the lessons of the preceding labs, each one also offers a unique opportunity to showcase some clever design and implementation to share with classmates and friends (Figure 1).

Lab	Title	Description
1	Orientation, Equipment Training and LED Light	Where we introduce the Interactive Device Design lab, and show students the basics of using the oscilloscope, multimeter, power supply, soldering iron and lab materials. Then students build a basic LED light circuit.
2	Frankenlight	Where students apply what they've learned about basic electronic components to control an LED light for some specific purpose of their own devising.
3	Digital Timer	Where students learn to make sounds, use resistance-varying sensors, and an embedded microcontroller to drive a 16x2 graphic LCD.
4	Data Logger	Where students learn to use voltage-varying sensors and log the incoming data to the microcontroller's EEPROM storage.
5	Etch-A-Sketch	Where students use graphical displays, then read from, and write to, external flash data storage.
6	Barebones MP3 Player	Where students build a simple MP3 player, something to ensure a modicum of success on their eventual final project.

Table 3: Lab assignments and descriptions/goals for each of the first six weeks of the term, after which students work on their final design projects.

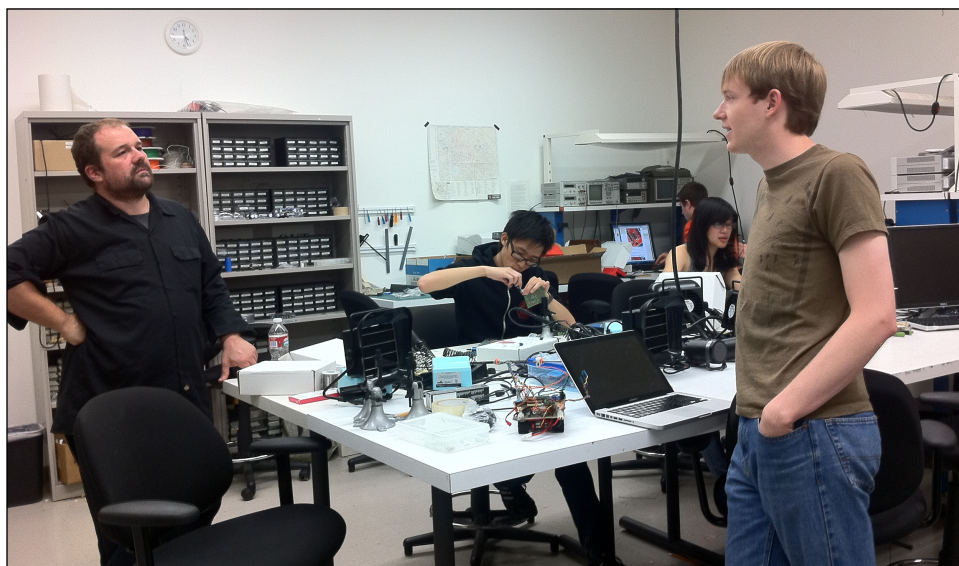


Figure 1: Students in the Interactive Device Design lab discussing their project ideas with Massimo Banzi, one of the co-founders of Arduino, a popular microcontroller board and prototyping platform, and the basis for students' projects.

Labs begin by introducing a simple analog LED button-potentiometer circuit. For most students, this is the first working circuit they have ever assembled, which can be quite exciting. In working with this passive circuit, students find that they can recreate behavior (such as light switches or dimmers) in the world around them, with the simplest of components, on the first day. This sets the stage to introduce a microcontroller into the circuit, allowing for programmatic control over the same tasks and more, such as making the LED *breathe* like many laptops do when asleep. The final task for these first two labs is to create a *Frankenlight*: a useful, switched LED lamp

built by hacking LEDs into an existing (functional or not) electronic device. One student recently opened a computer mouse, tapped the signal from the internal encoders, drilled two holes in the outer housing, and inserted LEDs through them, which flashed as the mouse moved.

Each subsequent lab develops the knowledge required to implement one or two particular functions of an MP3 player, and encourages students to be creative in their interpretation of the tasks that the lab presents to them (Figure 1). For example, the third lab introduces the microcontroller's built-in timers, along with resistive-varying sensors. The timers will eventually be used in students' MP3 players, to transfer brief segments of audio data from flash memory to a hardware audio decoder. But the task presented to students at this time is to build a timer that "*does something interesting*" when time expires. There is no prescription for the timer's task, or resolution, or what that *something* is. Some students build alarm clocks, others build games, such as comparing how quickly competitors can repeatedly tap a force-sensing resistor.

The next two labs introduce alternative ways to store, retrieve and present data, along with voltage-varying and count-based sensors. Presenting data that reflects current state is central to most audio players' interface: to display which track is currently playing, or up next, or power and volume status. But for the third lab, the task is to create a digital Etch-A-Sketch, using a graphical LCD instead of the original device's aluminum powder panel, and having the ability to save and retrieve sketches. Students frequently draw inspiration from elements of the Etch-A-Sketch's interface, including clearing the screen when turned upside-down and shaken (Figure 2).

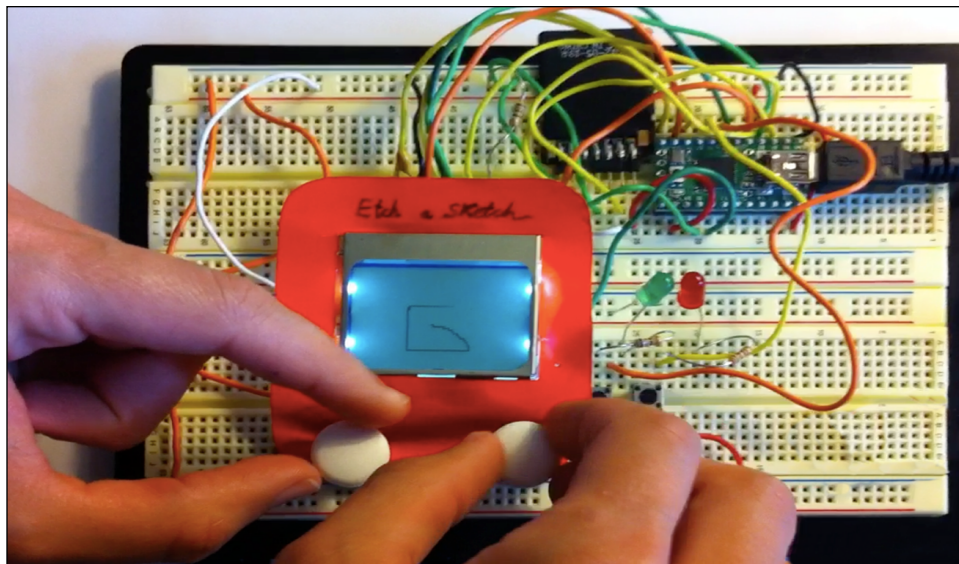


Figure 2: An example Etch-A-Sketch project for lab 5, with a graphic LCD for the display and two potentiometer knobs. Lab assignments are typically designed and built on protoboards, as shown here.

The final lab is to create a barebones MP3 player, which introduces the hardware and software required to decode and play audio data, and ensures a modicum of success on the final project. An important lesson of the barebones MP3 player lab is to understand non-blocking algorithms:

event-driven programs composed of functional threads that do not exclude the completion of other threads.

Homework: Broadening Students' Design Skills

Whereas labs emphasize practical hands-on building, homework assignments are oriented to guide students in design: articulating desires and alternatives, researching users and usage contexts, thinking through functional requirements, and acknowledging practical issues such as interface design and components sources.

The first homework assignment, begun during the first class session, is to dissect and analyze an audio greeting card. We ask students to informally sketch a few diagrams: functional block, mechanical and/or electrical, and user interaction. Our goal is not to assess how well they understand the card or its technology, but to introduce the different perspectives involved in the design, as well as the use, of interactive products. The second homework assignment is to fabricate a prototype MP3 player housing—really just a customized box—using rapid/additive manufacturing techniques. Even though students do not yet know what their projects will be, this small task starts them ideating, working with new materials and methods, and thinking in three dimensions. Some students prefer to craft more immediately usable products, such as cases for their mobile phones, or organizers for their lab supplies (Figure 3).



Figure 3: An example housing/box for homework 2, intended to hold small sketching and lab tools, and fabricated on a laser cutter from masonite and acrylic.

The third homework asks students to photograph five people as they listen to music, and for each one, answer the question “*this person needs a way to...*”, then include a few features that might be useful in that context. The exercise draws students’ attention toward users and their needs, activities and environments, and potential solutions. About one-third of final projects are founded on needs or insights that students discover during these observations. Each of these first three assignments also includes readings from the interaction design literature, to raise students’ awareness of current and historical concepts and controversies, as well as leading figures, in design practice. The last two homework assignments ask students to develop and then refine/update

a final project plan, building up from details such as required materials, their cost, and the time required to source them, to key design challenges such as evaluating which features could be removed if time becomes scarce, while still presenting a viable, working music player.

Design Project: Sending Students Into the World, Bringing Them Back

The final design project takes the last four weeks of the ten-week term, and follows a structured design process that includes planning, observation, ideation, prototyping, implementation and reflection/documentation. Students typically work individually on projects of their own choosing, although they are allowed the alternative to work in pairs, and are guided by regular check-ins with the teaching staff. Early on, students are encouraged to select a specific point-of-view informed by field observations, reflection and testing. During check-ins, instructors review sketches and notes, and prompt students to justify their design rationales, consider alternatives, and encourage exploration and divergence. Very quickly however, the tone switches to the practicalities of implementation and convergence. In this way, students gain experience in finding, as well as in solving, real-world problems. We also show students how to design projects that are *always finished*. That is, students' designs should account for the possibility that they may not complete all that they intend—perhaps due to very ambitious goals, difficulties building features, or delayed delivery of a specialty component—and should therefore move from working prototype to working prototype, building outward from features that they already have implemented.

The range of projects is very diverse, although a few patterns have emerged. Students who are particularly new to engineering typically stay close to the barebones player developed in the final lab. We encourage these students to be creative in one area of either software or fabrication: perhaps adding a song list feature, or crafting a simple but elegant housing. Students who are more experienced often prefer to introduce wireless communication (such as bluetooth to a mobile device) or stretch out through novel sensor circuits, which they design from the ground up. A medical student constructed his own finger-mounted pulse oximeter, while a mechatronics student designed his own myoelectric sensor, embedded within a wrist band. Both of these sensors were then used to select songs from a list to match, or influence, the wearer's current physiological state. Other students dig deeper into the datasheets for the hardware provided, and utilize features that are not implemented in the software libraries provided for the barebones MP3 player of the final lab. For instance, some students apply the MIDI features of the MP3 decoder chip to create musical instruments such as drum machines, theremins or electric guitars, rather than MP3 players (Figure 4).

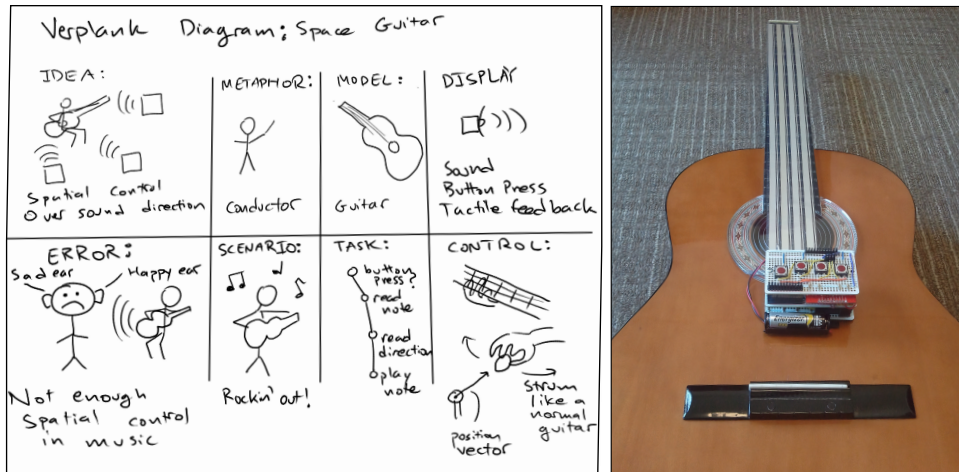


Figure 4: On the left is a Verplank Interaction Diagram, a framework for assessing different key aspects of a design.¹³ On the right is the final project, a digital guitar with linear soft membrane potentiometers, to address the spatial sound control issues that the student had identified.

4 Assessment and Experiences

Interactive Device Design is oriented toward students just entering engineering, who are interested in exposure to hands-on electronic design, so it is often their first experience in managing a design project of their own devising. As such, it is also their first experience setting initial goals, moving these goals as they become experts at their problem domain, handling setbacks, and pacing themselves for a final push to complete, document and present a project at a public event (learning outcomes a and d). It can take some convincing for students to realize that they, rather than the instructors, are the final authority on setting and moving goals or pacing themselves. Due to this latitude, students are assessed not so much on their point grades on labs and homework assignments, but on the depth and clarity of thought in their project motivation, how well their solution addresses initial needs, how well they allocated their time and resources, and their ability to communicate, even to teach, their newfound knowledge to others.

This ability to communicate and teach is exercised through a project design document, couched in a way to guide future students on how to recreate each aspect of a student's project, from initial design sketches and point-of-view, to state diagrams, photographs of prototypes, CAD files, and videos of users interacting with projects (learning outcome e). Students are encouraged to post these documents on Instructables, a website that hosts user-created, do-it-yourself projects.

To reinforce the emphasis on engineering communication, each lab has students create a video of their design and post it to the class wiki (often mirrored at YouTube). By viewing a subset of videos that are selected and presented during lectures, students can see what their classmates are doing, so they can gauge their own progress, as well as find inspiration for their next lab's video or project. But more importantly, they learn how to tell a story about very technical work. They discover what interests other people and what does not, how long they can hold someone's attention, and how narration, framing, editing and timing can shape viewers' perceptions.

Upper level undergraduate and graduate students have indicated on course applications and teaching evaluations that they selected the course for its open-ended project experience, since they do not often have the opportunity to scope the front end of design projects in their other coursework or research. Those who already have design experience typically take the course to gain technical skills for specific goals that they have: to support their research, or learn to use prototyping and fabrication tools (learning outcomes b and c). In our experience, advanced students do not use the open-ended nature of the final project to scope an easy task for themselves. Rather, they are motivated to scale projects to their knowledge level and skill sets, and adapt assignments to learn how to do things that they have wanted to do for a while. Most often, we have to check students' ambitions, and ask them to develop Plan B's and Plan C's, just in case something unexpected affects their progress.

5 Conclusion

We have approached Interactive Device Design as an experiment in changing the way that we approach engineering education. As we look to increase the general electronics literacy of students of all backgrounds, we might consider some of the ways that this course is distinct from other introductory electrical engineering courses. First, it is centered around practical knowledge and making, rather than first-principles understanding. In many ways, the course provides students with experience in tinkering and fabrication that those in previous generations might have already had from servicing cars or repairing transistor radios, only building upon the contemporary open-source hardware and maker movements. Second, the final project is the creation of an interactive device that is familiar, yet presents opportunities for rediscovery. The personal and demonstrable nature of the project, centering on students' own needs, or the exploration of someone else's, motivates great effort and a wide range of invention. We often hear students say that they want their family to see what they have learned at university, or that their projects are intended for someone particular. Third, designing labs and a final project having well-structured and guided core activities, as well as opportunities for open-ended adaptation, makes it possible for the same course to address the needs and goals of a wide variety of students. Moving forward, our challenge will be to integrate these aspects of the course into more traditional engineering courses.

Acknowledgments

The use of hobbyist electronics tools, sites and forums helped the instructors support an increasing number of students pursuing open-ended design projects. The course is only made possible through the existence of resources like Arduino, Instructables, YouTube, Sparkfun and Adafruit.

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