A "HANDS-ON" COURSE IN CONSUMER ELECTRONICS DESIGN*

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Abstract—There is still a large gap between the academic design approach taught to our students and the real world of competitive product design. In spite of program upgrades which heavily emphasize design, the termination of many of our students' advanced design projects is still a maze of breadboards connected together with wires which randomly wander off to input sensors or output displays. Clearly, there is a big step missing between the disorganized connection of components which concludes a design project, and the sleek, injection molded, Sony Discman that is playing in the design laboratory beside the workbench. In an effort to close the gap between engineering education and modern consumer electronics product design, the Department of Electrical Engineering at the University of Washington has initiated a "reverse-engineering" course in Consumer Electronics. The first offering of the course was made during Winter 1994 as part of the College of Engineering honors program.

INTRODUCTION

Engineering Education is undergoing a period of rapid change. Industry needs engineers who can design products which are competitive in quality and performance in an increasingly aggressive global marketplace. There is a sense that dividing Mechanical, Electrical, Industrial, and Computer engineers into separate compartments may produce only locally optimal designs. In education, the traditional emphasis on single-student analysis within an "Engineering Discipline" is giving way to interdisciplinary, design-team oriented education.

With these global trends in mind, we are developing a series of new laboratory-based courses with the general theme of "Design of Consumer Electronics," to address the need for interdisciplinary, design-term oriented education within the College of Engineering at the University of Washington. We have already taught one offering (ENGR 498H—Winter 1994—an honors senior elective), and will teach a second offering (EE 498—Fall 1994—an Electrical Engineering senior design course) in Fall 1994. We are offering a reduced version of the course as part of a workshop for disabled students during Summer 1994. Additionally, we are working to incorporate aspects of the Consumer Electronics course into the ENGR 100 Freshman Design program.

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http://isdl.ee.washington.edu/CE/ConsElectHome.html
In its Winter 1994 offering, the course included a laboratory in which students from electrical engineering, mechanical engineering, civil engineering, aeronautic and astronautic engineering, technical communications and computer engineering collaborated in small teams to disassemble, measure, and analyze a variety of models of CD players. The teams took on various subsystems including the optical train, focus and tracking servos, digital-to-analog conversion, data encoding and error correction, and disk handling.

We also encouraged a mode for the course in which the students presented design concepts for radically new consumer products based in CD technology. These designs varied from the relatively straightforward (wireless headphone links to CD players) to the wildly outlandish (levitating portable CD players using gasoline powered model airplane motors).

The course is still in its initial, experimental phase. Throughout the first offerings, we plan to adjust the learning objectives, content, and format to obtain optimal results.

RELATED WORK

As far as we can determine, no previous articles have been published about Engineering Design courses created around consumer electronic products. A related area which is attracting the attention of educational innovators is "mechatronics" [1–4], which is the tightly integrated design of microcomputing, actuation, sensing, and control. The University of Tokyo established a Department of Mechano-Information in the 1980s to help break down some of the disciplinary barriers which impede education in this economically important area. The University of California at Berkeley has recently started a Master's graduate degree program in mechatronics. Various courses in mechatronics have been offered nationally and internationally. However, to our knowledge, none has developed a laboratory focused on consumer electronic products.

Two of these mechatronics courses have been described in the literature, one undergraduate course in the U.K. [3] and another at the Master's level in Japan [1]. Both courses have taken a classical pedagogical approach in which a hypothetical mechatronic system is decomposed and the elements are taught in sequence. For example, the lecture plan for the British course is as follows:

(a) Foundation
(b) Microprocessors and Software
(c) Sensors
(d) Actuators
(e) Control
(f) Digital Techniques
(g) Robotics
(h) Applications

These courses differ from our courses in important ways. First, neither embraces the team approach that we propose to make a cornerstone of our new courses. Secondly, neither uses ubiquitous consumer electronics products as a source of "case
"Hands-on" course in consumer electronics design

There is a common misconception among many engineers that modern miniaturized electronic consumer products are monolithic devices which come out of an elaborate automated clean room and have "no user serviceable parts inside". In fact, a few hours in the laboratory with a screw-driver reveal a different story. Clearly, many of the functions of modern devices are implemented in VLSI Application Specific Integrated Circuits (ASICS) and thus are difficult to "reverse engineer". However, the functions of transduction, mechanization and control, are inherently available for observation because they interact with the device's environment. Our experience is that an astonishingly large number of subsystems within consumer products are accessible to reverse-engineering. For those that are not, we have had very good luck with constructing "scale models"—that is, models that illustrate all of the salient functions of the sub-system but perhaps at slower speed or with poorer resolution.

COURSE STRUCTURE

The goals of these courses are to expose engineering undergraduates in several disciplines (primarily Electrical, Mechanical, Industrial and Computer Engineering) to the realities of modern consumer electronics product design as well as to improve their ability to work in coordinated, heterogeneous teams. Students will form into interdisciplinary design teams which mimic the structure of small companies. These design teams then analyze, test, and redesign subsystems within existing consumer electronics products such as CD players, camcorders, computer hard disk drives, recordable mini-disks, digital compact cassettes, digital audio tapes, and so on. The combination of the small design teams and the use of real products will introduce the students to a more realistic model of industrial design activities.

Modular course structure and documentation

The structure we have developed for these courses is composed of self contained educational blocks. We use the term "course segment" or simply "segment" to describe the educational experience derived from a specific part of a consumer electronic product, and the course activities associated with that educational experience. We use the term "text-module" to describe a document which contains the relevant educational material for that course segment.

The course segments each have a specific learning objective and are based on functional subsystems or components of the selected consumer electronics products. For example, for the CD player, we have developed course segments for the Motor drive and focus control system, D/A conversion, encoding, decoding and filtering, and Laser and optical train (Fig. 1). These segments are highly interdisciplinary, crossing domain boundaries traditionally associated with the Electrical Engineering, Mechanical Engineering, and Computer Engineering disciplines.
Fig. 1. For the CD player, we have developed course segments for the Motor drive and focus control system, D/A conversion, encoding, decoding and filtering, and Laser and optical train.

Learning objectives

Each course segment has a specific learning objective. The learning objectives drive other aspects of the segment design.

Sample learning objectives include the following.

"Study the focus tracking control system for a CD player and understand the relationship between the mass, stiffness, damping and PID controller parameters of the mechanism to the rise time, overshoot, and frequency response of the system."

"Study the photonic and optical pathway for the CD player and understand the use of laser diodes, polarizing filters, cylindrical lenses, and four-quadrant detectors, in achieving the required degree of focusing accuracy."

Because our classes typically contain students from heterogeneous backgrounds, the objective is interpreted individually for each student. A learning objective may require demonstration of depth for a student whose preparation is closely relevant, and breadth for one whose preparation is in another field. In order to maintain flexibility, learning objectives are continuously modified between or during course offerings. Additionally, students are encouraged to define and modify the learning objectives for themselves and their design teams through their individual experiences and discoveries.

Additional learning objectives will cut across the course segments. For example, a key objective of the course is to convey the interconnectedness of subsystems through the product's mass, volume, and power limits. Students will measure the mass, volume, and power of the subsystems and relate them to the system's total through creation of mass, volume, and power budgets, and compare various brands for these attributes.

Laboratories

The laboratory activities for each segment proceed roughly through the following two stages.

Step 1. Introduction. Students disassemble the products, identify the subsystems and the interfaces between them. Students observe voltages and currents, forces and torques, wavelengths, etc. as they are generated by the system during operation.
Step 2. Analysis of subsystems or construction/analysis of scale models. Students use basic principles to analyze and predict various parameters (voltages and currents, forces and torques, wavelengths, etc.) of the subsystem. For some systems, the students will be able to measure the parameters in the working subsystem and compare the measurements to their predictions. For others they will need to construct a “scale model” (or measure parameters off an existing scale model) of the subsystem and predict the performance of the scale model.

As a specific example, in CD players, it is relatively straightforward to measure the voltages at the tracking photodetector as a function of position and observe how the control system responds to change in these voltages. Thus, it is possible to disassemble a CD player and isolate just the tracking mechanism for student study.

However, the majority of digital to analog conversion and filtering in a cheap portable CD player occurs in a single custom chip. Thus, it is very difficult to illustrate the operation of one-bit conversion, noise-shaping, and filtering. For this case, it is highly advantageous to construct a demonstration circuit on a breadboard which clearly isolates the various circuit functions (Fig. 2).

Final design synthesis

Design synthesis is key to the learning process. However, it is not trivial to propose and implement new design concepts for a consumer electronics project in the course of a single 10-week course.

As an alternative, we are developing the concept of a “living scale model”. Unlike the scale models that the students build in Step 2 of the various segment laboratories, this is a scale model which remains with the course from quarter to quarter. Physically, it is an ungainly thing, with all of the discrete subsystems separated from each other and cabled together. All of the subsystems are represented—some by student-built circuits, and some by disassembled components.

As the concluding project for each offering, each student group picks a subsystem from the scale model and attempts to “improve” upon it. The improvements could be

![Diagram](image-url)

Fig. 2. It is very difficult to illustrate the operation of one-bit conversion and filtering. For this case, it is highly advantageous to construct a demonstration circuit on a breadboard which clearly isolates the various circuit functions.
as simple as adding a different filter to the D/A converter, or as complex as replacing the existing subsystem by a new student-designed and built version.

Text modules

Because no textbook is available for this course, a key aspect of this project is the creation of "text modules". These "text modules" are concise documents which the students and instructors will develop from quarter to quarter. At the beginning of the quarter, each student group receives the "text module" developed by the last student group to study the subsystem. The students then develop and extend the modules, incorporating what they have learned. This "daisy-chaining" is a very dramatic way to teach good writing—because the past documentation is NEVER as complete as the present student team wishes!

For the text modules to be disseminated and reused from year to year, they should be able to stand independent of any particular make and model of consumer device. Even though consumer electronics products are available everywhere, it is unlikely that identical models will be available in all years, and at all locations. Fortunately, because of the requirements for standard media formats, the most basic aspects of the designs are standardized (physical dimensions, physical principles, data rates, etc.). Therefore, it is possible to make most of the segments' content independent of make and model. It is also of great value to the students to COMPARE different designs among consumer products and to try to deduce the relative advantages and disadvantages of the different designs. Thus, we are encouraging the text modules to include multiple design approaches from different makes and models.

The text modules are being continuously developed by students and faculty. They are currently being integrated as World Wide Web (WWW) pages [5] and will be interlinked with student reports. For the Autumn 1994 offering, we plan to have all text modules, course information, and student assignments encoded in the WWW page markup language, HTML. Student assignments will be turned in electronically in HTML and will be linked with the other course material. A pointer to the Consumer Electronics "Home Page" is given at the beginning of this paper.

COURSE ORGANIZATION AND DELIVERY

Our eventual goal is to select a different electronic product (such as a CD player or VCR) each quarter as the focus of study. So far, we have concentrated on CD players because of their relatively low cost, great student appeal, and interdisciplinary nature. Due to the work required to develop text modules and laboratories, we have not yet moved on to other devices. However, when text modules are complete for a quarter or semester course using the CD player, we plan to move on to camcorders. We hope that through electronic distribution and sharing of this material on the Internet, a wide variety of text modules will become available from many sources. For the future, we are exploring a number of other product choices ranging from electric toothbrushes to VCRs. However, we recognize that we must exercise some care when considering some consumer products for laboratory use. A few products which will
have special difficulties for the laboratory are cellular phones (radio-frequency interference and fraud potential) and CRT based TVs (high-voltage danger). We will not attempt to develop course segments based on these types of technologies unless we can get extensive support from industrial experts.

Prior to the first class meeting, the students are provided with some basic information on the selected product. This information includes commercial data sheets, technical articles, and the current version of the “text modules” for that product. A book which we have found quite useful for the study of CD players is *The Compact Disk Handbook* by Pohlmann [6].

The students will form design teams under the guidance of the professor. The various engineering disciplines will be balanced among the design teams. The design teams include older students (seniors and returning students with experience) as well as younger students (sophomores and juniors). Each design team has a designated “project manager” (an experienced junior or senior), “senior engineers” (generally experienced juniors and seniors) and “junior engineers” (generally inexperienced sophomores and juniors).

In the next year or two we plan to have freshman and sophomores participate as “apprentice” members of the design teams, with no more than one lower division student per team. They will help out the team with whatever tasks they can, and in the process, try to learn as much as they can in a “just in time” fashion. Perhaps more importantly, they will see how the fundamental ideas they are learning in their other courses relate to real-world products of the kind they use every day. This is intended to be a motivational experience for their future engineering course work. They will able to take the course again for credit at the senior level.

The course was initially offered as three lectures per week—with laboratory time available as convenient for the student. This was not found to be successful, as the open-ended nature of the laboratory activities makes it essential to have faculty present during some part of the laboratory session. Thus, we are moving toward a two lecture—one three-hour laboratory format where the faculty member is present during the three-hour laboratory session. The laboratory will be open for student use at other times—however we feel that the presence of a faculty member during some part of the laboratory session is critical to help guide the students’ efforts.

We also found it very successful to include guest lecturers as part of the course. These can include domain experts from within the University to lecture on subjects such as lasers or Reed–Soloman coding, as well as speakers from industry who can give perspective missing from the academic environment.

In the laboratory, the teams will have at least one product per team to disassemble and test. In practice we have found three good sources for reduced price consumer products. One source is large volume dealers (such as Silo and Costco) in the period immediately after Christmas. These organizations get a large number of returns that have been opened. They are generally willing to sell them to the University at a greatly reduced cost (typically 20–40% lower than retail). The other source is pawnshops. Pawnshops will occasionally take in electronic equipment that they later find to be uneconomic to repair. They are more than willing to sell dysfunctional or poorly functional equipment for a nominal price. (The best deal we found was eight CD players, including two platter units, for under $180.) Finally, unclaimed repaired units are often available from repair shops for little or no cost. Besides their low cost,
these "scrounged" devices are also useful because they illustrate older technology. It is quite instructive to compare different generations of consumer products to observe the methods used for cost reduction in newer generation equipment.

In a few cases, destructive tests or radical disassembly may be necessary (the pawnshop units are great for this), but for the most part, the devices will last for several offerings of the course. Appropriate security measures such as sign-out, recording of serial numbers, and indelible marking are used to prevent loss. However, we have not had any great security problem. We attribute this to the fact that the electronic equipment we are purchasing is typically much lower in quality than that actually owned by the students.

This proposed format is new and we expect some difficulty in achieving the right pedagogical balance. Two main difficulties have arisen so far. First, it is difficult to recruit students from a broad spectrum of departments (EE, CSE, and ME are our targets). Many students feel that they will be at a "disadvantage" "outside" their home discipline. We hope to address this problem with better marketing of the course, broader faculty participation, and new evaluation methods.

The second problem arises because of the breadth of topics needed to "totally understand" a system like a CD player. Our background as educators tends to drive us deeper and deeper into the component technologies. In a quarter, or semester course, it is impossible to treat all of these elements with the depth normally expected of senior engineering students. We hope that this will be countered by the horizontal themes such as the mass, volume, and power constraints, as well as by the detailed laboratory experience with real-world products.

In spite of these difficulties, we feel that the strong motivational theme of the course suggests a high probability of success and its relevance to national engineering challenges suggests a significant impact. To ensure success, we are experimenting with the format of the course during its first few offerings. During the first offering (Winter 1994 as an honors class) the course was a highly interactive student-driven one. Student design teams explored several subsystems in parallel and presented their findings to each other in a series of oral presentations. This "parallel" format has the advantage of exposing the students to the issues that arise when diverse subsystems are integrated into a single product. We discovered it especially valuable in the honors class as the students came from very diverse backgrounds.

In the "serial" format, which will be tried in Fall 1994 (as a senior level elective in Electrical Engineering), the class will consider three segments (Motor drive and focus control system, D/A conversion, encoding, decoding and filtering, and Laser and optical train) in series, with all groups doing a series of laboratories and design exercises on the same segments. This latter format has the advantage of greater pedagogical structure. We expect this form to be more successful with a homogeneous student background.

In either form, the final weeks of the quarter focus on documentation. The "text modules" will be upgraded to include the students' efforts of the current quarter. The students will give presentations and demonstrations of their designs. We feel that the ability to give a clear presentation is a key skill which is missing from traditional engineering education. In our previous courses, we both have had the experience that this is something the students pick up rather rapidly after seeing their own presentations in direct comparison to others in the class.
Awards will be given for the best designs, the best presentation, the best time management by a design team, and the most creative effort.

CURRICULAR DETAILS

The course was first offered Winter 1994 as an honors design course (ENGR 498H) open to College of Engineering honors students. Non-honors students were encouraged to take the course on a space-available basis. During the 1994–95 academic year, ENGR 498H will be expanded into a general design course open to all College of Engineering students. (This course has been approved as EE 498 and is officially scheduled for Fall 1994.) In the 1995–96 academic year, the scope of the course will be extended to freshman and sophomore pre-engineering students. Extension of this course to freshman and sophomore students will be accomplished in conjunction with the College of Engineering’s participation in the National Science Foundation ECSEL consortium for restructuring undergraduate engineering education.

EVALUATION

We believe that the assessment aspect of this design program is critical to its long term success. We are working with the University of Washington Office of Educational Assessment (OEA) to develop a realistic assessment plan. One method developed by the OEA is the “Small Group Instructional Diagnosis” process for student feedback. This is a mid-course student evaluation conducted as a “focus group” organized by a trained staff consultant from OEA.

DISSEMINATION OF THE COURSE

Dissemination of the course will primarily be via the “text modules”. These modules are visualized as “living documents” that are continually revised by students and faculty. A kernel “text module” will be created by the course team prior to the first offering of a class using this module. The module will include: background and history of the device, market statistics, physical principles and equations governing the subsystems, how the physical principles relate to performance specifications, trade-offs between cost, weight, and volume and performance, and so on. These “text modules” will be continually upgraded by students in the course and by the faculty. Each “text module” will be made available to the students in the following course—who will, in turn, revise and upgrade it.

The text modules will be shared among institutions via the Internet. Currently available WWW browsers support text, graphics, binary files, sound and movies, and we plan to include any and all formats as appropriate. All student reports will be included in the document web, and students will be encouraged to include links to the explanatory basic material in the electronic reports.
RELATIONSHIP TO OTHER CAMPUS ACTIVITIES

We plan to work with a number of other campus agencies to disseminate this unique design experience among a wider group. In August 1994, we worked with Dr Sheryl Burgstahler of the DO-IT program (Disabilities Opportunities Internetworking Technology) to host a two-week summer educational experience for handicapped students. Students in the program learned about the basic operating principles behind consumer electronics devices and had the opportunity to disassemble and test the devices.

Our new courses are a small experiment in changing the nature of undergraduate Engineering Education. We hope that the students’ experience will be relevant to their future product and system design experience in a variety of industries. We feel that today’s consumer electronics products, in daily use by virtually every university student (and professor), are highly optimized systems which will serve as excellent models for student engineers.

The University of Washington has made a strong commitment to changing the nature of the engineering core curriculum college-wide. A significant part of this effort is the curriculum restructuring supported by the ECSEL program. However, Electrical Engineering participation in the ECSEL program has been limited—not just at the University of Washington, but coalition-wide. We plan to use this class as a mechanism to strengthen the link between Electrical Engineering and the ECSEL program. Initially, we propose to work with Dr Gretchen Kalonji (UW ECSEL P.I.) to implement a module of the Freshman Design class in ECSEL during the 1994–95 academic year.

This will be an experiment in which simplified versions of the course segments are derived for this use. Depending on the success of this module, the interaction may be expanded to the sophomore level. These results would be disseminated via the ECSEL network. Finally, we are in the process of establishing a link to the Minority Science and Engineering Program.

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REFERENCES