AC 2007-1223: EMBEDDED SYSTEMS EDUCATION VIA DISSECTION

J.W. Bruce, Mississippi State University

J.W. Bruce received the B.S. degree from the University of Alabama in Huntsville in 1991, the M.S.E.E. degree from the Georgia Institute of Technology in 1993, and the Ph.D. degree from the University of Nevada Las Vegas in 2000, all in Electrical Engineering. Dr. Bruce has served as a member of the technical staff at the Mevatec Corporation and the Intergraph Corporation. Since 2000, Dr. Bruce has been with the Department of Electrical and Computer Engineering at Mississippi State University, where he is an Associate Professor. Dr. Bruce teaches courses on embedded systems, VLSI, and systems-on-a-chip design and was named the Bagley College of Engineering Outstanding Engineering Educator in 2003. Dr. Bruce received the John A. Curtis Lecture Award from the ASEE CoED in 2004. Dr. Bruce performs research in embedded systems design. He is the author or coauthor on more than twenty-five journal articles, technical publications, and book chapters. He is a member of IEEE, Eta Kappa Nu, Upsilon Pi Epsilon, Tau Beta Pi, and ASEE.

Lee Hathcock, Mississippi State Univ.
Embedded Systems Education via Dissection

Abstract

For years, biology and zoology education has required the dissection of small animals to aid in the understanding of physiology and anatomy. Dissection provides the student with the ability to peer inside the inner workings of biological bodies to see how the pieces fit together in a very physical way. But, in the end, the biologist only “analyzes” physiology, and only rarely gets to “synthesize” a similar design. Engineers, on the other hand, spend most of their careers designing devices and systems. It seems only logical that engineers would benefit as much, or more, than biologists from dissection exercises. This paper describes the experiences of the author with dissection of consumer electronics in an offering of a semester-long embedded systems class for seniors and introductory graduate students. Example dissections will be presented and discussed. The paper will detail how the dissections furthered the class toward its educational objectives. Finally, qualitative comments from students will be provided, along with observations from the instructor.

Introduction

Mississippi State University has recently revised its undergraduate computer engineering (CPE) program with input from alumni and advisory employers. The CPE program has focused on embedded computer systems. Embedded systems form a rich application source through which CPE education can be made relevant. Embedded computer systems are a timely subject that is immediately useful to students in their senior design projects. Furthermore, a large number of our CPE graduates currently use or design embedded computer systems in their jobs.

Recently, a team-based progressive embedded systems design course was developed that, in addition to providing the technical embedded systems knowledge, develops team and communication skills in situations emulative of industry. The course was a success by many accounts; however, student teams abandoned sound design practices in attempt to meet the demanding 16-week “time-to-market” constraint. Team members produced defect-riddled designs and the design schedules slipped due to an unproductive test-redesign-test development cycle.

Later, the course was retooled to use a lightweight design process based loosely on proven software engineering standards which detects defects during design. This development process has been used with success in the subsequent offerings of the design course based on a more complex project. The resulting student designs are typically on time and of high quality. Furthermore, students report satisfaction with the experience, because of both the visible results at course end and the perceived relevance of the process that they used.

All of these course offerings have made a visible impact on the computer engineering program at Mississippi State University. Computer engineering student projects in the capstone design course have greater complexity and are of higher quality compared to previous years.
While the impact on the quality of designs in the capstone design course is clear: many more student teams were achieving functional final senior designs. However, a large number of these functional student designs were not readily manufacturable or cost-effective. Students simply were concentrating on the first-order functionality and ignoring higher-order design constraints like packaging, cost, manufacturing costs, etc.

With fundamental embedded systems content being taught in the Mississippi State University's junior level course$^4$, the senior level embedded systems course is free to concentrate more on system concepts and integration issues that are more common in engineering practice and industry, like team-based design$^{2,3}$, industry-based software engineering standards$^{5,7}$, and the higher-order design constraints that students lacked in the capstone design course. It was decided that students should somehow be made aware that design functionality was not the sole criteria for measuring success.

Design is a creative process. There are no recipes for design, and design should be taught like other creative human processes – through apprenticeship and experiential learning. But, how does an university professor mentor dozens of students with a real-world design? How could students have time to gain exposure to quality designs and still learn the material required by the curriculum? How can students quickly gain the major effect obtained by years of design experience? I decided that real, tried-and-tested, designs would be crucial. Furthermore, students would need to be exposed to many different designs in relatively short order. An idea was born: Why not dissect many different electronic products? A quick search of internet found that dissection was used in a few mechanical engineering programs$^9$, but was relatively rare in ECE programs. (I found a few programs where dissection had been used with ECE students, but most programs were multi-disciplinary in nature and many has discontinued the practice.)

**Dissection**

A thorough understanding of the “anatomy” of an electronic product will help the electrical and computer engineer in the analysis of electronics and embedded systems. But even more, it will help the engineer in designing future products. I firmly believe that dissection should be an integral part of design education, especially in the upper-level courses where systems are complex. To this end, students in the author's senior-level embedded systems course at Mississippi State University were assigned the task of acquiring a low-cost, widely-available consumer electronics product. Then, students were instructed to “tear it apart” in a very controlled manner, while documenting every step. Dissection products could cost no more than US$15, must contain digital electronics, and be battery powered. No two students can dissect the same product.

Students must ascertain the product's complete electrical schematic and measure the product's entire physical make-up. Dissected products are analyzed to determine the theoretical battery lifetime and tested to verify that reality matched student computations. Students were instructed to compose a bill of materials, estimate manufacturing costs, and relate the product's cost to the manufacturer's suggested retail price. The dissections must also contain the complete set of product use-cases and include timing diagrams for all real-time functions. Students must make
the end result of their dissection available to classmates and the world via the world wide web\textsuperscript{10}. To ensure that students read all product dissections, students are asked to score each dissection in several categories. The top-rated dissection in each category is awarded bonus points on the dissection grade.

Since all dissection journals were to be read by all students, I prescribed a specific form for the dissection journals. With all students very familiar with the structure of the dissection journal, the student's orientation time is minimized when starting to read about the dissection of a new product. The following section will describe the dissection journal structure, as well as an example from a student dissection. (The screenshots are difficult to read, but I wanted you to get a feel for the general form of the dissection journals. You can read the journals in detail online\textsuperscript{10}.)

\textit{Introduction}

Students were instructed to describe the product, its market, its high-level operation, and any other nontechnical aspects.
Students must determine the product’s history, the manufacturer’s suggest retail price (MSRP), discounted street price, retail outlets, and if other rebranded or OEM version are available for sale.

**Product market and retail information**

Students must determine the product's history, the manufacturer's suggest retail price (MSRP), discounted street price, retail outlets, and if other rebranded or OEM version are available for sale.
Figure 2: Dissection Journal: Product Market Analysis

**Dissection Photo Journal**

Starting with a photo of the product in unopened, retail packaging, students dissect the product, taking photos at each step along the way. These photos will help others understand the manufacture and operation of the product. Furthermore, the photos will constitute a reassembly procedure.
Figure 3: Dissection Journal: Dissassembly Photo Journal
Product Operation

Over the course of the dissection, students must determine the function of each product component. A high-level block diagram must be made for all electronic and mechanical subsystems. Details of electronics operation must be made as far as is possible. All the way to a circuit schematic with full BoM is ideal. Use case timing diagrams are required for each unique product operation mode.
Figure 4: Dissection Journal: Product Operation
Product Analysis

A photo inventory of each unique (and removable) part must be made. Each mechanical part should be identified as to its composition and weighed. PCBs or other impractical assemblies do not have to be disassembled to each individual part. However, each assembly should be inventoried and a complete list of components formed. Estimations of mass for each component should be made for undissected mechanical assemblies.

Figure 5: Dissection Journal: Product Analysis I
Product (Re)assembly

Any special procedures for product assembly should be noted and documented. This particular dissection was reassembled in reverse order as the disassembly.

Student Feedback

Upon completion of the semester-long course, students provided qualitative and quantitative feedback. Qualitative feedback was provided through a modified Likert scale survey with student responding with -2 for “strongly disagree”, -1 for “somewhat disagree”, 0 for “neither disagree

Figure 6: Dissection Journal: Product Analysis II
or agree”, +1 for “somewhat agree”, and +2 for “strongly agree”. Using a bipolar scale allows for easier interpretation as negative numbers indicate disagreement, positive numbers indicate agreement, and a zero indicates no preference. The table below gives the average student response (and variance) for the survey questions.

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>mean</th>
<th>variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 The dissection was helpful in forcing me to grow in my engineering abilities.</td>
<td>1.3</td>
<td>0.46</td>
</tr>
<tr>
<td>Q2 I learned more about engineering analysis from the dissection activity.</td>
<td>1.3</td>
<td>0.68</td>
</tr>
<tr>
<td>Q3 I learned more about engineering design from the dissection activity.</td>
<td>1.3</td>
<td>0.23</td>
</tr>
<tr>
<td>Q4 My “hands-on” skills improved because of the dissection activity.</td>
<td>1.1</td>
<td>0.54</td>
</tr>
<tr>
<td>Q5 I learned more about manufacturing from the dissection activity.</td>
<td>1.3</td>
<td>0.68</td>
</tr>
<tr>
<td>Q6 I learned more about economics from the dissection activity.</td>
<td>1.2</td>
<td>0.62</td>
</tr>
<tr>
<td>Q7 I learned more about ethics in engineering from the dissection activity.</td>
<td>0.0</td>
<td>0.89</td>
</tr>
<tr>
<td>Q8 My future designs will be different because of what I learned in the dissection activity.</td>
<td>0.5</td>
<td>0.72</td>
</tr>
<tr>
<td>Q9 Preparing the dissection journal helped me to become a better technical writer.</td>
<td>0.3</td>
<td>1.12</td>
</tr>
<tr>
<td>Q10 Preparing the dissection journal helped me to better understand my product's operation and design.</td>
<td>1.3</td>
<td>0.46</td>
</tr>
<tr>
<td>Q11 I learned more about engineering from reading other people's dissection journals.</td>
<td>0.7</td>
<td>0.90</td>
</tr>
</tbody>
</table>

*Table 1: Student self-assessment survey results*

The data in Table 1 shows that students clearly felt that performing the dissection activity improved their ability to analyze and synthesize designs. Refer to results for questions Q1-Q6 and Q10 and recall that the largest possible score is 2.0. These results are encouraging as the students' self-assessment indicates that the students felt the activity was worthwhile.

The result on Q7 in Table 1 seems to indicate that students felt that the dissections did not impact them ethically, even though a sizable portion of a lecture was spent in discussion about the ethical uses of dissection in the workplace. Clearly, I need to do a better job of making an impact in this area. I was disappointed with the results on Q7-Q9 and Q11. The students indicate only “very light” impact on their technical writing skills by preparing the dissection journal, and a bit more impact on their abilities from reading the other dissection journals. Finally, the result in Q8 seems surprising to me given the strong scores in Q1-Q6. The students indicate in Q8 that they only “marginally agree” with the statement that their future engineering designs would be different because of what they learned in the dissection. More data and investigation are clearly needed about the usefulness of the dissection.

Qualitative responses were obtained when students were asked to describe the thing that the dissection activity taught them most. The responses include
• The dissection taught me about real embedded systems. Like dissecting a frog, I was able to
learn about the inner workings of an embedded system. But unlike the frog, I can cut the
device open and it is still works, allowing me to active observe the device’s operation. The
dissection gives me the confidence to take a device apart if I need to do so.

• The dissection taught me that electronics do note bite. Don't be afraid to take them apart.
Also, I now look at everything and wonder if it has an MCU inside. If it does, how is it being
used? What algorithms does the device use?

• The dissection taught me that if you are making a few devices, keep your non-recurring
engineering (NRE) costs low. If you are making a million devices, go NRE crazy to get your
Bill-of-Materials (BoM) low.

• The dissection taught me to never underestimate something that looks simple.

• The dissection taught me that even simple circuits can be marketed and sold.

• The dissection taught me the importance of economics on engineering design.

• The dissection taught me that even though something seems overwhelming, jump in head-first,
and things will begin to fall into place.

Furthermore, students were asked to described the components of the course that they like the
most, and liked the least. Two students commented that the dissection was the single, best part of
the course, while one student felt that the dissection was the worst part of the course. The
remainder of the students felt the lab experience or lectures were the best part of the course.
Several students responded to other questions about how they felt the dissection and the course
will benefit them in the capstone design course and in their future careers. Whether or not the
capstone course designs improve is still to be seen.

Conclusions

This paper described the experiences of the author with dissection of consumer electronics in an
offering of a semester-long embedded systems classes for seniors and introductory graduate
students. Students disassembled and analyzed a low-cost device. The results of this dissection are
published on the web. Students were required to read and rate all dissections in several
categories to ensure that each student was familiar with other designs. Qualitative and
quantitative data was collected from the students about the perceived effectiveness of the
dissection activity. The students felt strongly that the dissection activity improved their skills as
engineers, but did not rate the impact on their soft skills (ethics and technical writing) very
strongly. The true impact on the students will not be known until they complete their capstone
design course projects. Hopefully, they are now aware of manufacturing and economic issues of
design.
References


