Education & Training

Editor: Scott F. Midkiff ■ Virginia Tech ■ midkiff@vt.edu

An Undergraduate Success Story:

A Computer Science and Electrical Engineering Integrative Experience

Grant A. Jacoby and Jean R.S. Blair

EDITOR'S INTRODUCTION

On 4 May 2006, I had the pleasure of being a judge at Projects Day. This event, held by the United States Military Academy's Department of Electrical Engineering and Computer Science, culminated a year-long capstone design experience for fourth-year cadets. I invited Grant Jacoby, an assistant professor, and Jean Blair, professor and director of the computer science program, to describe the capstone design courses and particularly one team's work in pervasive computing. Your comments and suggestions for this column are welcome. Please contact me at midkiff@vt.edu. *—Scott Midkiff*

At the United States Military Academy (www.eecs.usma.edu), every student majoring in CS or EE participates in an *integrative experience*, an interdisciplinary effort comprised of two successive, 3.5-credit courses and culminating in a final prototype project. Students with a computer science major take CS 401/402 courses and those with an electrical engineering take EE 401/402 courses. Both CS and EE 401/402 introduce essential elements of design and project management. They require students to draw on their cumulative academic experiences to address an open-ended, real-world design problem as a team.

The CS students must first successfully design, build, and test software and electronic systems or subsystems for small, well-defined problems; EE students explore this process cycle on several increasingly larger problems. In parallel with their "toy" problems, we also assign students from both sets of courses to a unique team project, with a goal of satisfying the needs of a client, who is either a faculty member with a specific research product need or an actual client with a product requirement.

This client-oriented, team-based experience gives undergraduate students their first hands-on research and development experience in a carefully monitored and guided environment that translates theory into product.

THE INTEGRATIVE EXPERIENCE

Course requirements include periodic in-progress reviews, written and oral reports, and completion of the iterative design, build, and test cycle for a functional system. Additionally, the design must consider the project's social, political, technological, and economic aspects. Table 1 lists the CS and EE 401/402 courses' major deliverables in chronological order.

Working with undergraduate students on essentially graduate-level endeavors necessitates extra attention. For example, weekly meetings are absolutely essential to ensure that progress is made. What undergraduates first fail to grasp is that you can't conduct research by pulling an all-nighter to catch up at the end. You need little steps that occur frequently and with oversight. To prod their involvement, we also had regular peer evaluations in which team members evaluated their fellow teammates' contributions and efforts.

Similarly, you need to also hold the faculty advisors accountable. Not all teams do poorly because they do poor work; some are poorly guided. In short,

QUICK FACTS

Courses: Electronic Systems Design I and II (EE 401/402); Software Systems Design I and II (CS 401/402)
Unit: Electrical Engineering and Computer Science
Institution: United States Military Academy
Instructors: Aaron J. Ferguson and LTC Carl Fossa (2005–2006)
Advisor: LTC Grant A. Jacoby (2005–2006)
Level: Fourth-year undergraduate

Published by the IEEE CS and IEEE ComSoc ■ 1536-1268/06/$20.00 © 2006 IEEE

EDUCATION & TRAINING

TABLE 1
Deliverables for CS and EE 401/402.

Computer science	Electrical engineering
A system requirements specification	A problem statement
A system design documentation	Block diagrams and system specification
A test plan	Recommendations of subsystem parts needed and criteria used to evaluate them
A prototype system demonstration	A decision matrix outlining different courses of action
A paper	Three distinct design reviews: preliminary, critical, and final
A user manual	A working prototype
The final working system	A paper

the course director must monitor advisor involvement throughout project development. Advisors generally mean well, but most also have numerous competing interests. Consequently, they can find themselves as much behind schedule as their team and unable to surge to meet deadlines and standards.

GOALS AND OBJECTIVES

CS and EE 401/402 aim to successfully execute an engineering design methodology as a team. To help students successfully complete the courses' objectives, we set specific goals. Students must

- identify what they must know and do to successfully complete their project,
- identify what they don't currently know,
- identify and satisfy user requirements,
- independently learn new technologies and skills, and
- integrate new skills and technologies during the design process and into their completed projects.

Finally, before graduation, each interdisciplinary team must demonstrate a working prototype for Projects Day.

The two sets of courses have varying objectives to meet these goals. For both classes, students must

- effectively lead and work with peers as part of an interdisciplinary design team;
- identify risks, schedule and budget resources, and follow through on project planning;
- evaluate and select new technologies based on economic, political, and social uncertainties;
- learn and apply new technologies;
- clearly articulate client requirements;
- complete a detailed project design;
- respond to changing project circumstances;
- deliver a completed product to the client;
- formulate project results for a scholarly audience; and
- describe project results to a nontechnical audience.

Computer science majors must additionally consider HCI during all stages of design. Electrical engineering majors have more emphasis placed on improving their ability to effectively communicate technical material using specific engineering words and terms precisely.

The objectives listed are meant to encourage an intellectual stretch. By this, we mean encouraging students to take theory learned in their earlier courses and create applications that integrate hardware and code to produce a prototype that meets customer requirements. Typically, undergraduates seldom delve into work other than what occurs in controlled lab environments or what has already been solved. Our approach supports the idea that students can learn more by participating in actual prototype development as part of a multidisciplinary team. This approach also helps prepare them for employment in both commercial efforts and higher levels of academia.

THE GIBRALTAR CAPSTONE PROJECT

We chose the Gibraltar capstone project to showcase a successful integrative multidisciplinary research project. Gibraltar is a hardware and software system designed to combat the threat of attacks on mobile devices by using their smart batteries, other 802.11 traffic, and registry-related indicators for attack detection and prevention. Although mobile devices are globally omnipresent, security developments for these devices haven't kept pace with their technological advancements. By default, most of these devices are poorly configured for security, and present-day security measures don't deliver practical solutions.

Team Gibraltar was a joint EE and CS team, consisting of two electrical engineering majors and three computer science majors. They based their work originally on successful battery-based intrusion research. The EE and CS department's Information Technology Operations Center (www.itoc.usma.edu)—whose primary mission is to conduct cooperative research to innovatively improve information assurance—also lent direction to their work.

The name Gibraltar alludes to the "Rock of Gibraltar" in the sense of an observation point for all that goes in or out of a particular region. The

TABLE 2
Student workload distribution.

Primary role	Student major	Job description
Project manager	Cadet Warders (CS)	Management of meetings, project progress, scheduling, and resources. Development and coding on a registry editor and on a remote application of Gibraltar.
Coding and implementation	Cadet Hickman (CS)	Development of technical components for Gibraltar's detection and protection capabilities.
Testing and professional documents	Cadet Castle (CS)	Design and research to ensure proper testing of use and misuse cases. Development of signal algorithms.
Hardware development	Cadet Darensburg (EE)	Design and implementation of the signal conditioning circuit and signal capture hardware.
Hardware development and software implementation	Cadet Griffin (EE)	Design and implementation of signal manipulation tools, including a digital signal processor.

team aimed to apply this concept to wireless, host-based security in a novel and practical method. They aimed to build an efficient host-based software and hardware system that helps protect mobile devices and their networks from attack by correlating and analyzing relevant data pulled from these devices, individually and collectively. Table 2 shows how they distributed their workload according to requirements and skills.

The team quickly surmised that a mobile device's intrusion protection system is at odds with itself. It should run as often as necessary and remain transparent to the system and its users. However, it should use as few system resources as possible to detect, report, and prevent intrusions. In a growing market segment that offers little information assurance, they deduced that a critical need existed. If they could develop a fundamental approach to a protection method that could flexibly, nonintrusively, and efficiently embrace wireless security evolution, the large consumer base clearly indicated that their efforts would be a noteworthy contribution with a potentially large return on investment.

After several months and hundreds of hours of work, Team Gibraltar found a unique method to combat a range of security threats. They began monitoring demands placed on battery current (mA) as well as correlating power and event activities, such as processes, network traffic, open ports, and registry keys.

To accomplish this forensics-oriented transformation, they used the battery signal as a reference to device usage, without needing to conduct more complex scans that persistently use processing cycles. Gibraltar's combination of power and system-activity monitoring serves as an early-warning, tripwire-like sensor for mobile hosts, blocking and identifying attacks. Examining and correlating these constraints and activities created an effective monitoring agent on end platforms that are conventionally considered a network's weakest security link.

In effect, Team Gibraltar provided totally host-based, proactive intrusion protection that's inexpensive, easily integrated, and readily available. This novel enhancement for detecting, alerting, and responding to various intrusions on mobile devices complements virtually any network intrusion-detection system already in place.

LESSONS LEARNED

This client-oriented, team-based approach clearly meets the objectives of the integrative experience. Other course designs could also achieve these objectives, but this approach imparts some particularly advantageous lessons.

Preparing for what's next

The work students undertake in building a prototype gives them experience and helps them prepare for graduate school, the marketplace, or both. For instance, in an academic context, they learn to understand that research doesn't always offer a clear-cut answer, unlike the classroom problem sets seen previously. Moreover, they develop familiarity with the design, build, and test methodology, preparing them to use this process in their future work. This experience could easily distinguish them from other undergraduates when applying to graduate school or for a job.

Building awareness

Another less obvious outcome is the students' level of awareness of the scale and depth that their work can entail. The more they dive into a particular area, the more they realize how much they still have to learn. Although undergraduates encounter a broad range of subjects, they rarely explore them deeply. Building a working prototype of this level requires a much deeper understanding of the work at hand. This might also involve areas that don't sit squarely in the student's selected major. For example, one CS major on Team Gibraltar was responsible for articulating, coding, and comparing two mathematical algorithms that highlighted the sta-

EDUCATION & TRAINING

Figure 1. Team Gibraltar at Projects Day.

Figure 2. Cadets presenting their work at the RIT IEEE Student Design Contest.

tistical significance of the test results collected by the team's EE majors. This work was critical in linking the work of both sides to harness, collate, and analyze data from both hardware and software activities. The student's newfound math abilities helped bring the team's work together, highlighting how the students converted theory into practical application.

Understanding ROI

Students also learned more about ROI. If their product won't quickly provide a profit margin, a commercial enterprise might not support its development. Social benefits, while desirable, usually give way to economics. Finding the right economies of scale for a technology to be profitable is an area most undergraduate CS and EE majors have never considered before. For example, the ability to build items that operate faster, more accurately, and cheaply impacts time to market and cost considerations. Requiring teams to articulate this initiates an understanding that will help them long afterwards.

BEYOND EXPECTATIONS

Gibraltar's development was an integrative experience that not only met the desired goals but exceeded expectations, partly due to the project's interdisciplinary nature; partly to the enthusiastic, motivated, and capable students; and partly to the faculty's dedicated development efforts.

Interdisciplinary cooperation

Working on a platform that allows for multidisciplinary cooperation offers many benefits and lets students share knowledge and experiences from diverse backgrounds. The richest benefits come when walking a mile in the shoes of a fellow team member from a different discipline. We asked each person various EE and CS questions regardless of the student's major. To ensure that each team member understood all aspects of the problem domain and chosen solution method, they weren't permitted to ask other team members for assistance in answering these questions. This *accountability technique* encouraged discussion among all members throughout the entire design and development process—regardless of their primary roles.

True integration

As the students worked together to build their product for Projects Day (see figure 1) in early May, they competed in three additional judged events: regional, multiregional, and national. The first project competition was at the National Conference for Undergraduate Research. This event required a series of presentations to demonstrate and promote undergraduate achievement in research and scholarship, but only one team member was allowed to attend. Thus, the student (an EE major) had to understand all facets of the project to make a concise and informed presentation.

The same situation occurred during the next competition, the regional Third Annual Scintilla Forum sponsored by the Mid-Hudson Technology Council. In this case, only two CS majors were available to present, but they still performed well enough to take first place.

All five team members attended the next, local competition at Projects Day. However, as several judges converged on the team at once, each member had to answer a range of questions. They couldn't hand off specific questions outside their main scope because the other members were also engaged in their own discussions. The team was prepared for this, but the judges weren't, commenting afterward on how this demonstrated a truly integrated team—the poster child for it, so to speak.

The final competition was the multiregional 6th Annual Rochester Institute of Technology IEEE Student Design Contest (see figure 2). Even though the entire team couldn't attend, Team Gibraltar received the "Best Presentation" award, voted not only by the judges but also by advisors from the 22 other teams represented.

Graduate-level publication

One of the biggest accomplishments from an academic standpoint was the submission of an undergraduate-produced paper to the 2006 World Congress in Computer Science, a graduate-level conference. The paper appeared in the conference proceedings, so team members gained a citation as well as an appreciation for the process of writing a technical conference research paper. Few undergraduates conduct real-world research and fewer still have them published before they graduate. The authors now have an accolade to distinguish themselves in their graduate school applications, and they understand more of what most graduate programs will require from them.

We felt that asking undergraduates to acquire an appreciation for the work required to go from a working prototype to an actual product was a bridge they weren't ready to cross, nor did we have sufficient time within the course. The scale of effort between the two is generally far greater than it is from lab to prototype. Nevertheless, some of them will learn this on the job soon enough.

Gibraltar's accomplishments showcase not only what a motivated multidisciplinary team can do in nine months but also the positive impact it can have on students and society afterwards. Although projects like this require extra effort from everyone, the potential benefits are both immediate and long-lasting. For example, the amount of one-on-one mentorship our faculty provides students enables project teams to often perform at graduate levels. We hope this approach will serve as a beacon to other academic science and engineering programs. P

ACKNOWLEDGMENT

The views expressed herein are those of the authors and do not purport to reflect the position of the United States Military Academy, the Department of the Army, or the Department of Defense.

Grant A. Jacoby is a lieutenant colonel in the US Army and a senior research scientist in the Information Technology Operations Center in the Department of Electrical Engineering and Computer Science at West Point. Contact him at grant.jacoby@usma.edu.

Jean R.S. Blair is a professor of computer science at the United States Military Academy and the director of the computer science program in the Department of Electrical Engineering and Computer Science. Contact her at jean.blair@usma.edu.