

Senior Capstone Design Experiences for ABET Accredited Undergraduate Electrical and Computer Engineering Education

Ashraf Saad, PhD
Department Head and Associate Professor
Department of Computer Science
School of Computing
Armstrong Atlantic State University
Savannah, GA 31419
ashraf@cs.armstrong.edu

Abstract

Capstone senior design experiences are both a graduation requirement for undergraduate engineering majors and for ABET accreditation of these programs. A senior design course is typically the last bridge for students between undergraduate education and the engineering profession in their respective disciplines. The course differs from other lecture and laboratory based courses in the engineering curriculum in fundamental ways. We describe these fundamental differences and present our experience in advising students for semester-long capstone design projects in electrical and computer engineering at the Savannah campus of the Georgia Institute of Technology over a period of four years between 2001 and 2005. We give details about the course objectives, structure, outcomes and related assessment. We also give details of completed projects, all involving software and hardware development and integration, with several projects dealing with the development of algorithms and applications for mobile robots. We conclude with the lessons learned, observations and recommendations that should be of value to engineering educators.

Keywords: senior design, electrical and computer engineering education, undergraduate capstone design experience.

1. Introduction: Senior Design in Engineering Education

Capstone design experiences, also known as senior design projects or senior capstone projects, are critical to undergraduate engineering education. They are required to provide undergraduate students with the

opportunity to solve open-ended real world problems in their respective engineering disciplines prior to graduation. They are also requisite by the Accreditation Board for Engineering Education (ABET) for accreditation of undergraduate engineering education programs [1]. While such experiences are typically expected to take place during the senior (last) year of the undergraduate curriculum, they can range in duration from one semester to a whole academic year, and may also be interleaved by co-op or internship experiences in industry. Consequently, the senior design course is typically the *last bridge* for students between the undergraduate engineering curriculum and the engineering profession. However, senior design differs in fundamental ways from other courses in the engineering curriculum that are lecture or laboratory based. In this paper we describe these differences and present our experience in advising students over a period of four years (between 2001 and 2005) for semester-long senior capstone projects in electrical and computer engineering at the Savannah campus of the Georgia Institute of Technology (GT-Savannah) [2]. This paper is structured as follows: in section 2 we give an overview of capstone design experiences, their nature and their importance to engineering education, in section 3 we give details about our capstone design course objectives, structure, outcomes and related assessment, in section 4 we give details of completed electrical and computer engineering capstone design projects, all involving software and hardware development and integration, with several projects dealing with the development of algorithms and applications for mobile robots, in section 5 we present our observations and lessons learned, and in section 6 we conclude the paper with recommendations that should be of value to engineering educators, especially those involved with undergraduate electrical and computer engineering education.

2. Senior Capstone Design Projects: An Overview

Design courses are required to provide engineering students with authentic design experiences that are akin to what they will encounter *in the real world* when employed in industry upon graduation. Currently, programs for electrical and computer engineering (ECE) education strive to get students to experience design at various stages:

- During the Freshman year: to increase students interest and motivation in ECE studies [3].
- In standalone courses: in support of specific course objectives and learning outcomes [4].
- During the Senior year: as a semester-long capstone design experience [5,6].
- Throughout the curriculum: to sustain student preparation and interest in ECE in a more holistic and integrative manner [8].

ECE students at Georgia Tech experience design in the context of several standalone courses throughout the curriculum [4] and in a one semester senior capstone course as well [5,6]. The importance of senior design to other engineering disciplines has also been reported, for instance: for biomedical engineering education [8-10] and for industrial and systems engineering education [11]. The senior design course differs fundamentally from other undergraduate ECE courses, principally in the following ways:

- *Close ended versus Open Ended Problems:* The capstone experience should *by design* be structured so that students deal with an open-ended design problem. In addition to fulfilling ABET requirements, this gets undergraduate students in their senior year to go through an experience akin to what most of them will encounter when employed by industry upon graduation, that is: being in charge of identifying a solution to a real-world problem that is not known a priori, generating and evaluating alternative designs, and making various design and implementation tradeoffs. Moreover, tradeoffs do not only deal with technical constraints, but they also have to address design constraints that are non-technical in their nature, such as economical, regulatory and environmental ones.
- *Unique Answers versus Multiple Solutions:* Solutions to problems in core ECE courses of the engineering curriculum are *unique*, i.e., permitting a single correct answer, with the solution typically found in the instructor manual. In contrast, by its very nature, the design process admits multiple

possible solutions, none of them is known a priori, and identifying the design that will ultimately be implemented involves an iterative process. One major implication for instructors that is due to this difference is in the way assessment and grading are conducted: while grading in core engineering courses relies mostly on student performance on exams that admit unique quantitative answers, assessment of student performance in capstone design courses must take into account the project based nature of the course.

- *Individual Work versus Teamwork:* Core ECE courses typically require individual effort by students on all assignments, laboratory projects and exams. In contrast, students must work in teams for the whole semester on their senior capstone projects. This is to ensure that students get to experience teamwork in the capstone course, similar to the experience of working on projects in industry, prior to graduation. Once again, the teamwork aspect of senior capstone projects calls for different ways of assessment.
- *Course Structure:* Most core undergraduate ECE courses are lecture and/or laboratory based, are instructor led, and student learning is expected to be in lock step with coverage of the course content. In contrast, the senior capstone course is inherently project based and, as a result, the instructor serves as an advisor as well. Moreover, given that it is a semester (or multi semester) long effort, the course must have a project management structure to keep track of tasks, deliverables, and milestones.

3. Course Objectives, Structure and Outcomes

Several important educational objectives should be met by the capstone design projects for undergraduate ECE majors, including:

- getting students to address issues central to ECE education through system integration of hardware and software,
- giving students the opportunity to experience first-hand real-time programming and embedded systems, including various algorithms for computer vision, control and communications, and
- providing a “learning by doing” opportunity for students to develop and implement a solution for an open ended design problem.

Consequently, the main traits of the capstone experience provided to each ECE student at GT-Savannah, include:

- Working on a capstone project as member of a team of 2-4 students.
- Each team works on a project to develop a solution to an open-ended problem using both hardware and software.

A pre-course survey is conducted at the beginning of the semester in order to get a better appreciation of the background that each student brings to the capstone experience. Activities and deliverables for the capstone project comprise the following:

- Project Proposal: specifying user/problem requirements and specifications, proposed solution(s), and relevant industry standards, such as IEEE standards.
- Project Management Plan: a Gantt chart that lists all tasks, deliverables, and milestones, as well as the breakdown of duties and responsibilities by team member.
- Hardware and Software Acquisition: corresponding to the adopted design.
- Weekly Presentations and Progress Reports.
- Interim and Final Reports.
- Documentation: developing documentation in the form of [separate] user and developer manuals: the user manual provides a *turn key* explanation of how to operate the project deliverable while the developer manual provides details about the technical aspects of all hardware and software used and developed for the project.
- Final Presentation and Demonstration: of the completed project to the whole class.

Project assessment was also based on these activities and deliverables.

4. ECE Capstone Design Projects

The amount of time devoted to the capstone design experience varies by institution and by the major field of study. While such experience is typically expected to take place during the senior year, it can range in duration from one semester to a whole year, and may also be interleaved by co-op or internship experiences in industry. At Georgia Tech, ECE students complete the aforementioned requirements for a capstone design experience in a single semester-long (16 weeks) course (also known as ECE 4006 in the academic course catalog). Students are also required to take a course on professional practice and project management (ECE 4000) before being allowed to enroll in the capstone design course.

A platform of choice for intramural capstone design projects at GT-Savannah has been the Amigobot mobile robot [12]. Mobile robots have been used in a variety of settings in support of ECE education and related disciplines at varying levels of sophistication, for instance:

- to support teaching digital logic at the freshman/sophomore level: by getting students to develop the digital circuitry of a memory module in a constructivist, integrative manner [3],
- to support teaching an introduction to computer engineering and VHDL: by using an Altera board that is integrated with an Amigobot [4], and
- to integrate robotics research with undergraduate education: for ECE majors [6] and for related majors, such as computer science [13,14], and
- as the platform for capstone design projects: as realized with ECE students at the Developmental Robotics Laboratory (DRL) [5,6,7].

Capstone design projects completed by ECE majors using the Amigobot at GT-Savannah include:

- Embedded Computer Vision: Developed by a team of three students in the Fall 2002 semester for indoor robotic surveillance. The embedded digital video system they developed was equipped with a Sony® CCD camera that is based on the high bandwidth (400 MB/s) IEEE 1394 (Firewire) protocol. The resulting system was then used to implement digital signal processing for computer vision algorithms, such as Sobel edge detection. The team of students also compared the performance of communications algorithms to transmit the acquired images using TCP/IP over a local area network (LAN). The system architecture developed by this project and the implementation details have been reported in [5].
- Simple Mobile Robot Behaviors: A team of two students completed the integration of the CCD camera with the AmigoBot via a notebook computer (a lightweight Sony Vaio® PC) in the Spring 2003 semester. A track-following mobile robot navigation behavior based on edge detection computer vision algorithms was developed. A demonstration of this project by the undergraduate students was one of the highlights in the Open House of the engineering programs at GT-Savannah in May 2003.

- Surveillance Applications: The system requirements for capstone projects in Fall 2003 consisted of developing the mobile robot behaviors for indoor and outdoor surveillance applications by two teams of two and three students each, respectively. In order to do so, additional sensors and the corresponding hardware and software capabilities were acquired and integrated with the AmigoBot. For indoor surveillance, in addition to the CCD camera integration (similar to the system described above), images were transmitted using TCP/IP-based wireless communication to a remote computer. Moreover, the AmigoBot could be controlled using a joystick over the wireless connection thereby enabling teleoperation (an area also pursued by other educators; e.g., [15]). For outdoor navigation, a GPS receiver was interfaced to provide the coordinates needed to generate the robot trajectory. Some insights from both projects for robotic surveillance include:
 - For wireless transmission of a video stream: the conversion from JPEG frames to TCP/IP packets, and achieving a feasible frame rate for real-time wireless transmission and edge detection for hallway navigation.
 - For using a GPS for outdoor trajectory following algorithm: taking into account the resolution provided by a handheld GPS, as well as the conversion of the GPS longitude and latitude coordinates provided to the robot Cartesian coordinates.
- Advanced Sensor Integration: A team of four students undertook the development of a Sensor Integrated Security Robot (SISR) in Fall 2004. They set out to integrate a variety of sensors, namely: a digital compass (based on a pair of Philips KMZ51 magnetic field sensors), a flame detector, touch sensors, and a low-cost CCD camera to the Amigobot via the Sony Vaio® notebook computer used by previous projects. The purpose was to enable the robot to collect sensor data from the robot's surrounding for security and surveillance purposes. For instance, the flame detector can be used to program the robot with a fire seeking behavior, similar to the requirements for the fire fighting mobile robot competition [17]. Data is then transmitted using the Vaio's built-in IEEE 802.11b wireless adapter to a user at a remote computer via the building's LAN access

points. The fully integrated Amigobot is shown in Figure 1.

The following is a list of other capstone design projects completed in Spring 2005 by ECE majors at GT-Savannah under the advisement of the author:

- an Infrared Context-based Information System,
- a wireless temperature monitoring system, and
- a web-enabled clock.

5. Observations and Lessons Learned

Overall, all capstone design projects have been successful as confirmed by all completed projects over the period of four years (2001-05), according to official and informal course surveys at the culmination of each semester, and by follow up correspondences and feedback after graduation. The following are some observations that emanated from the experience to-date in advising undergraduate ECE students for their capstone design experience at GT-Savannah:

1. *Design Throughout the Curriculum:* Educators are indeed expanding design experiences throughout the undergraduate curriculum for all engineering disciplines at numerous institutions. Moreover, it is our experience that successful structured design experiences can help address some crucial issues for students, such as increasing motivation to study electrical and computer engineering early on in the curriculum [9]. Addressing these issues take on an added importance in the current era of decreasing enrollment in science, mathematics, engineering and technology (SMET) disciplines in the US.
2. *Open Ended Problem:* The capstone experience should be structured "by design" so that students deal with an open ended design problem in order to get undergraduate students to go through an experience in their senior year similar to what most of them will encounter when hired to work in industry upon graduation.
3. *Engineering Skills:* Valuable electrical and computer engineering skills that students got the chance to further develop and use in all capstone projects include the use of diagrams and system integration.
4. *Software Development Skills:* All capstone projects involved a significant amount of software and application development. Related crucial skills that students got the chance to appreciate first hand include providing documentation for their source code and investigating the use of open

source software and operating systems (such as Linux).

5. *Soft Skills*: Additional skills that are needed in the real world and that students get the chance to hone in the capstone experience include teamwork (each team comprised 2-4 students), communication skills: both oral skills, through weekly presentations, and writing skills, through interim and final reports, as well as an appreciation of project management, by getting them to estimate the cost (for equipment and personnel) of their respective projects and getting them to develop a Gantt chart for the project at the onset and updating it halfway through the semester – Figure 2 shows an example of such a Gantt chart.

In addition, all projects got students to address issues from multiple engineering disciplines, namely: electrical and computer engineering, mechanical engineering, and systems engineering.

6. Conclusions and Recommendations

For the aforementioned reasons, we believe that design experiences should be expanded throughout the ECE curriculum in a more integrative and comprehensive manner.

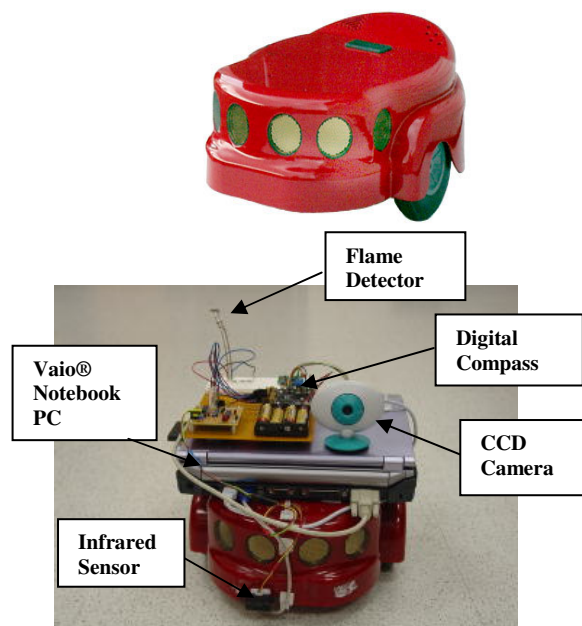


Figure 1. (Top) AmigoBot Mobile Robot from ActiveMedia®. (Bottom) Sensor Integration for AmigoBot.

Moreover, the use of an Amigobot as the platform for integrative capstone design gives undergraduate students first-hand experience with behavior-based robotics and with several issues in autonomous mobile robotics research, such as: sensing and perception, reasoning and decision-making, and human-robot communications. The demand for individuals with mobile robotics expertise continues to grow for both military and commercial applications. Future directions include expanding the opportunity for more undergraduate students to get involved in robotics research at the DRL to prepare them to take advantage of these career opportunities, as well as expand our outreach activities for robotics education to students and teachers in K-12 in our region.

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Biosketch

Dr. Ashraf Saad is Associate Professor and Head of the Department of Computer Science in the School of Computing at Armstrong Atlantic State University (August 2006 – to present). He was born in Cairo, Egypt where he received his bachelor of science degree in electrical and computer engineering with honors from Ain Shams University, Cairo, Egypt in 1988, and his master of science degree from the Cranfield Institute of Technology, U.K., in 2001. He received his doctorate in electrical engineering in 1996 from Vanderbilt University where he was a member of the Intelligent Robotics Laboratory from 1991 to 1996. From 1996 to 2000 he was assistant, then associate professor at the University of Cincinnati where he succeeded in securing two major NSF funded projects. He is the founder of the Developmental Robotics Laboratory on the Savannah campus of Georgia Tech. Dr. Saad is a member of the IEEE and ACM professional societies, contributor to a textbook and author/co-author of over 30 peer-reviewed journal and conference publications. He acquired R&D experience in software engineering through work and consulting appointments at high tech organizations in the USA, France, Japan, and Spain. He can be reached at: ashraf@cs.armstrong.edu.