THE CAPSTONE SENIOR DESIGN COURSE: AN INITIATIVE IN PARTNERING WITH INDUSTRY

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Abstract *– In the Department of Computer Science and Engineering at the University of South Florida, we use the required capstone senior design course to help students make the transition from student to industry professional. The course also plays a key role in achieving departmental ABET EC 2000 outcomes. We have partnered with local industry to bring non-proprietary, real-world hardware and software projects to our students. Industry partners contribute projects, mentor students, and give guest lectures. Students work in teams and have milestones and schedules. Project duration is one semester. Final presentations include a project demonstration, user documentation, press release, and poster. We find that our students perform very well when presented with a project that someone at the end truly "cares about" and will use. Evaluation results show that students see this as a very valuable course in the curriculum for preparing them for industry careers.*

Index Terms – Capstone, senior design, industry projects

INTRODUCTION

The capstone design course is a traditional part of most engineering curriculums. A capstone design course allows senior-level students to integrate their engineering knowledge and produce a useful engineering artifact. The capstone design course serves as a final preparation for students entering into industry. Increasingly, industry is emphasizing the need for graduates to have both technical skills and soft skills. Soft skills include the ability to work in teams, participate in project planning and scheduling, give presentations, and be able to deal with uncertainties in a professional manner. There are many possible models for a capstone design course. They include having students select their own individual projects, assigning projects to individuals or groups of students, and having industry participation. Industry participation appears to be a growing trend, and we are part of this trend in the Department of Computer Science and Engineering at the University of South Florida [2].

There are several models for industry participation in a senior capstone project. Some colleges use student selected or faculty assigned projects that are then judged by an industry panel at project completion. Student selection of a project can be entirely unconstrained, or can require the students to target their projects for a given platform or development kit. Historically, senior project courses were based on individually completed projects, but the trend seems to be towards team projects. Another model for industry involvement is for participation starting with project selection. The Integrated Product and Process Design (IPPD) program [5] at the University of Florida is a selective program enrolling approximately the top 25% of students in all engineering departments to work on industry-contributed projects in interdisciplinary teams of six students for a duration of two semesters. At North Carolina State University, an industry senior design center [3] was established in the Department of Computer Science in 1994. A collection of industry-contributed project ideas is maintained as part of this center. The focus of the capstone course at NCSU is on teaming, process, and professional communications. Many capstone courses emphasize both hard and soft skills. A national survey of capstone courses was completed by McKenzie et al. [4]. Table I is a (non-inclusive) collection of Web links to industry-based capstone design courses in departments that offer computer engineering and computer science degrees.

TABLE I
WEB SITES OF INDUSTRY-BASED DESIGN COURSES

University	Web site for CE and/or CS capstone course
Arizona	http://www.ece.arizona.edu/~ece498/
Mich Tech	http://www.ece.mtu.edu/pages/senior_design/index.html
NCSU	http://courses.ncsu.edu/ece480/lec/001/
NCSU	http://sd.csc.ncsu.edu/SeniorDesign/index.html
Oregon State	http://www.ece.orst.edu/industry/srprojectbrochure.pdf
Portland State	http://www.cecs.pdx.edu/capstone_student.php
UF	http://www.ippd.ufl.edu
USF	http://www.csee.usf.edu/~christen/class6/class6.html
UIUC	http://www.ece.uiuc.edu/corporate/design.html
UIUC	http://slappy.cs.uiuc.edu/cs292/

Our department offers degrees in Computer Engineering, Computer Science, and Information Systems. Both Computer Engineering and Computer Science are ABET accredited and follow the EC 2000 requirements. Our Senior Project course (CIS 4910) is required for Computer Engineering students and elective for others. We view this course as a very important component in the preparation of a trained computing professional. The course emphasizes both hard and soft skills and serves as an emulation of a real world project. We use projects contributed from local industry and partner the student teams with industry mentors. As a result of this course, students experience

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many real world events for the first time. Learning to deal with uncertainties – missed dependencies, difficult team members, even layoffs of industry mentors – is a very valuable learning experience. In this paper, we describe the development of our industry-based senior project course.

ROLE OF THE COURSE IN ABET EC 2000

Throughout the 1990's, a major concern of all programs preparing for ABET accreditation visits was design. A capstone design course was not only essential, but was also typically the major focus of interest for the accreditation team. The introduction of ABET's EC 2000 appeared to diminish the emphasis on design or at least to overshadow considerations of design with considerations of assessment. While it is true that the requirements for assessment were formidable, it is not the case that EC 2000 diminished the importance of design and the capstone design experience. More than half of the Criterion 3 (a through k) mandated outcomes involve abilities directly related to design, and Criterion 4 specifically requires that a student's curriculum have a culminating, major design experience.

If we consider these two ABET criteria, we will see clear guidance for what ABET would like to see in a capstone design course. According to Criterion 3, some of the characteristics necessary for well prepared graduates include the ability to: (a) apply knowledge of mathematics, science, and engineering; (b) design and conduct experiments, as well as to analyze and interpret data, (c) design a system, component, or process to meet desired needs; (d) function on multi-disciplinary teams; (e) identify, formulate, and solve engineering problems; (g) communicate effectively; and (k) use the techniques, skills, and modern engineering tools necessary for engineering practice. ABET 2000 Criterion 4 speaks directly to a culminating, major design experience which incorporates "engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political." (from ABET 2000).

A capstone design course has clearly not declined in importance within the ABET accreditation criteria. It provides one vehicle for the assessment of program outcomes. In addition, it continues to be viewed as a cornerstone of the professional requirements of a quality undergraduate engineering curriculum.

COURSE DESIGN AND IMPLEMENTATION

This section describes the departmental history of our senior project course, course objectives and implementation, working with industry, project and course phases, and final deliverables.

Departmental History of Senior Design Course

From its inception in the early 1980s, our department has recognized the value of a capstone design class. The course, as we offered it, was composed of the following stages:

1. A student would identify a project, either a product of his or her own interests or something suggested by a faculty member;
2. The student would identify a faculty member to serve as project sponsor;
3. The student would enroll in the Senior Project class and attend the 3 or 4 meetings of that class (typically one or two organizational meetings, a midterm update meeting, a final project presentation meeting, and infrequently a meeting with a guest speaker);
4. The student would work independently, with perhaps an occasional interaction with the faculty sponsor, to complete the project;
5. A demonstration of the completed project would be given for the faculty sponsor;
6. A 15 to 20 minute description/presentation of the project would be given to the entire class;
7. A final written project report would be submitted.

This approach had some good characteristics:

- A student with a strong desire to pursue a particular project had an avenue for gaining credit for that effort and likely invested significant effort in the project;
- There was little overhead for the department. Faculty sponsors served primarily as either sources for project ideas or as "governors", reining-in the overly ambitious and prodding the minimalists. Students rarely interacted extensively with their sponsors. The Senior Project course was a no-credit duty usually assumed by the department's Associate Chairman.

There were some less than desirable features of this course:

- There was very little topical constraint. In particular, many "toy" projects were undertaken while few projects bore resemblance to tasks the students would soon face as graduates;
- Students who did not have their own project ideas would frequently search desperately for both a sponsor and an idea and would consequently often have only minimal interest in their project;
- While students could elect to work as groups, most worked as individuals, thus missing an important extra learning experience;
- Although the burden of the project sponsor was not particularly onerous, it was rather unequally distributed across the faculty. This, coupled with the lack of official recognition of faculty effort expended, led to an absence of interest in the enrichment of the projects or the enhancement of the activities of the official course itself.

The combination of a course which we no longer felt proud of and our desire to promote both the learning experience of a team effort and a more constrained and realistic set of projects provided the impetuous for our extensive revision of the Senior Project course.

Course Objectives and Implementation

The Senior Project course (CIS 4910) is the capstone experience for seniors in the Department of Computer Science and Engineering. The goal of the revised course is for students to learn the product development process and complete a significant hardware or software project. The specific ABET-style learning objectives are:

1. Students will select an industry-contributed hardware or software project and form teams of size four to six based on their selected project
2. Student teams will follow a formal development process to complete their project.
3. Students will complete a requirements, specification and test plan.
4. Students will implement their design.
5. Students will test the resulting system.
6. Students will produce a written final report, poster, and press release describing their project. A final oral presentation and demonstration is also to be given.
7. In the process of meeting the course requirements students will experience all phases of project development and thereby will gain an appreciation of the demands of those project phases.

The course meets once per week for 75 minutes for lecture, supervised group work, exam, or guest lecture. The first three weeks of the semester are used to learn the product development process and to learn how to achieve the course deliverables. The students are expected to dedicate 3 to 4 hours per week outside of the class. The course outline is in Appendix A. Appendix B describes the course deliverables. The key question is, "Has the project met its requirements?"

Working with Industry

Having good support from industry is key to the success of this course. Our strategy has been to approach central Florida companies who hire graduates from our program. We focus primarily on companies within driving distance of the campus so that the students can easily travel to the corporate site (and the industry sponsors can travel to campus). We find these companies through our knowledge of the area employers and with some assistance from the College of Engineering development office. We "sell" the senior project course to industry in terms of two benefits to the participating company:

1. A first look at the graduating class for recruiting
2. An opportunity to have a non-critical path "back burner" problem solved.

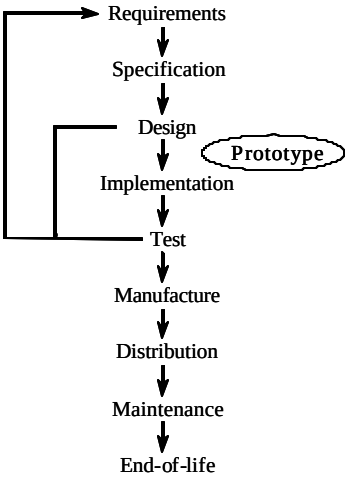

FIGURE. 1
THE DEVELOPMENT PROCESS

Even when companies are not currently recruiting, they can see a long-term benefit to being involved with their local university. We ask for three things from a company:

1. A carefully defined project suitable for completion in one semester by a team of four to six students. The project should be slightly open-ended (to force the students to identify the problem requirements), not on the critical path for the company, and non-proprietary.
2. A guest lecture to the class on any technical topic (recruiting is allowed, but the talk should not be purely a recruiting presentation). This guest lecture gives each company exposure to all of the students in the class and not only to its team of students. The students see a broad range of "real world" ideas and perspectives.
3. An opportunity for the students to present their project results at the corporate site. This adds a sense of importance to the project.

The amount of mentoring that a company provides to the students is entirely up to the company. Some companies have mentored students very closely, others less so. This difference in support causes occasional unhappiness among students, with some students feeling that the course is "unfair" if they get less mentoring than some other students.

Phases of the Senior Design Project Course

We teach a standard product development process as part of the course. Figure 1 shows the steps of the process. A key step is a prototype demonstration which we insert between design and implementation. At the prototype demonstration, the students must have running code and/or working hardware. An agreement (in the form of a mini-contract) is made between the students and the instructor as to what will be shown at the prototype demonstration. The deliverables in Appendix B follow from this development process. The

first three weeks of the semester are devoted to class lecture where we cover this development process. The student projects cover all the steps of this development process through test. Manufacture is a difficult step (and well beyond the scope of this course) for hardware products, but not difficult for software products. Distribution, maintenance, and end-of-life are not covered by the student projects in the duration of the semester.

The textbook used is Brooks' *The Mythical Man-Month* [1]. Brooks was the development manager for the IBM OS/360 operating system (for the IBM 360/270 series of mainframes). Brooks' teachings are timeless with his book having been republished as a 20th anniversary issue in 1995. The 1995 book also republishes Brooks' famous essay "No Silver Bullet – Essence and Accident in Software Engineering". The premise of this essay is that design (essence) and not implementation (accident) is the hard part in software development and that no tool (no magic "silver bullet") can reduce this difficulty. The book closes with a chapter-by-chapter introspection written in 1995 of the entire book. We supplement the textbook, quite literally, with handouts from the Dilbert cartoon strip. Much of Dilbert is very real (albeit exaggerated for comic effect) – and the students need to see this.

Final Project Deliverables

The project deliverables are staged through the entire semester. Each deliverable contributes to the student's class grade. The five final deliverables are:

1. Requirements document
2. Specification document
3. Prototype demonstration
4. Test plan
5. Final demonstration and presentation

The final demonstration and presentation puts together all previous documents in an updated form and includes a formal presentation, press release, and poster. Appendix B describes the project deliverables.

EXAMPLES OF PROJECTS

In three semesters of using this course, we have worked with ten central-Florida companies. Several companies have worked with us for all three semesters. Examples of four projects that show the diversity of the companies, types of projects, and student project results are:

Breed Technologies: Breed develops and manufactures products for improving vehicle safety; in particular, air bag related technologies. Breed had a group of students set-up an Intranet web site for the Breed R&D department. The contents of the web site were the general information of the R&D department, a listing of the core team members, description of the core projects, and the department's Labor Tracking & Report System (LTRS). The LTRS system tracked the labor rates, materials procurement, outside contracts, and fiscal budgets for Breed internal R&D projects. Students designed the LTRS and wrote the software (using Microsoft ASP) for the website. The students also organized the information on the website to be useful to Breed internal needs. The students' work is in daily use by Breed.

Catalina Marketing: Catalina develops targeted marketing services that use technology and information to reach consumers through many different media. One service that Catalina produces is the ability for cash registers to track consumer purchases and print appropriate coupons on the back of sales receipts. Catalina had a group of students explore solutions for compression of error logs to reduce dial-up line costs (e.g., from a failing cash register to the central Catalina headquarters). The desired solution was a C++ class that could easily be incorporated into existing Catalina software. Since the content of the error logs could be partially predicted, an innovative dictionary-based compression scheme could be implemented where the dictionary existed at both ends (and need not be transmitted as part of the compressed file). The status of the students' work is not known.

Sonny's Bar-B-Q: Sonny's is the largest Bar-B-Q franchise in the country with over 130 restaurants. Sonny's is always exploring new applications of computing technology to the restaurant industry. Sonny's has contributed projects to 1) explore the use of handheld devices (e.g., Visor and Palm PDA's) for taking orders at the table and with a wireless network send the orders to the kitchen and 2) explore the use of handheld devices for barcode inventorying of food products to reduce loss. Students designed and wrote software for the handheld PDAs to achieve the goals set by Sonny's. This work was intended as proof-of-concept and thus was not directly implemented by Sonny's.

Sypris Electronics LLC: Sypris is an electronics manufacturing and engineering services company serving the Department of Defense and the avionics and aerospace communities. Sypris asked a group of students to explore new methods of generating user passwords (for access to desktop computers and file servers). The generated passwords needed to be resistant to cracking by programs such as L0phtCrack, but also be memorable by a human. A user-friendly front-end for generating passwords was requested by Sypris. This project did not achieve very good results. The students produced a method that was not evaluated (and had potential holes for cracking of passwords) and hence was really not usable by Sypris.

EVALUATION OF THE COURSE

Our evaluation of the new version of the senior design course has three components. First, the modified structure of the course incorporates several features which we believe to be improvements. Because the previous version of the

course was in many ways like an independent study course, there was significant heterogeneity in the extent to which students were guided in the application of good project practices. The new version of the course assures that all students develop their projects with a disciplined approach. In the previous course team projects were uncommon. In the new version students are provided with a team project experience. Finally, the students now work almost exclusively with projects proposed by local industry. This provides the students with the stimulation of working on a practical project as well as allowing them to sample the sorts of tasks which they will soon be experiencing in the workplace.

A second component of our evaluation comes from student self-report. The first vehicle is a mid-term survey. While most of the questions are open ended and therefore difficult to summarize, two of the questions have more quantifiable components which relate to the modification made in the course. One question asks students the value which they place on the soft-skills (e.g., team work, presentation skills, etc.) which are being sharpened in the course. In the most recent survey, given the choices "They make or break your career", "Medium importance", and "Technical skills matter only", 20 of 22 selected the first choice and two the second. Another question asked whether the students felt that the course was providing a better preparation for industry than their other courses. Twenty said yes and the remaining two marked both yes and no and provided qualifying statements. It thus appears that the students responded positively to the new course. In addition to the course midterm evaluation, some of the students were graduating and contributed comments to a non-mandatory exit survey. One of the questions asked about their prior participation in any form of group project. For this past Fall's survey, all but one of the responders indicated previous group experiences: however, everyone also reported that the Senior Design experience had enhanced their ability to work as part of a team. It therefore appears that from the students' perspective they are gaining valuable soft skills, honing their abilities to function in teams, and gaining valuable preparation for industrial positions.

A final long-term evaluation is yet to be performed. In our survey of graduates two and five years after graduation, we will be adding questions which specifically address the perceived value of the Senior Design course. We will be able to compare the responses of those who had the earlier version of the course with graduates who experienced the revised version.

SUMMARY AND FUTURE WORK

We have described the evolution of our capstone senior design course from individually selected projects to one of industry projects and student teams. The course has gone from little supervision and structure to significant mentoring and structure as imposed by a development process. The course has also gone from one of unrecognized faculty effort to becoming a formal class (i.e., for assignment to a faculty member as part of their regular teaching load). We firmly believe that teaching students both hard and soft skills is important to their survival and success in industry. The abilities to work well with others and manage uncertainties are very important. A project with ambiguous requirements and missing dependencies is not "unfair" – it is simply the way it is in the real world and not the textbook world. It is an engineering challenge to best deal with these uncertainties.

In future semesters we intend to include weekly progress reports, agendas, and signed time sheets. We intend to add a full class design review where all students can contribute to the designs of other groups. We also intend to video tape final presentations so the students can evaluate themselves. As more of our students graduate and enter the "real world" we intend to evaluate the course from student, industry, quantitative, and instructor perspectives. We believe that partnering with industry for the senior capstone design course is very beneficial to the students, individual faculty members, college, and industry. We hope that our experiences with developing an industry-based capstone design course will be used by others. We believe that our model can scale well for both small and large institutions. We look forward to hearing from others with regards to their experiences.

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APPENDIX A – COURSE OUTLINE

This appendix contains the course outline from Fall 2002. The companies participating were CAE, Harris Corporation, Jabil Circuit, Inc., Sealund and Associates, Sonny's Bar-B-Q, and Sypris Electronics.

Week #1 – Introduction and kick-off

Project kick-off. Sign-up for projects. Development of ground rules and expectations. Discussion on establishing requirements.

Week #2 – Development process
Overview of the development process. Project planning and team work. Developing the specification.
Week #3 – Development process (continued)
Test plan and user documentation. Documentation of software. Giving effective presentations. Posters and press releases. Documentation of "yourself" – the resume. Requirements document is due.
Week #4 – Lecture overflow
Lecture overflow from weeks #1 to #3
Week #5 – Project Work Day
Open lab day for project work (in class). Will review draft specification/design documents.
Week #6 – Guest Lecture #1 (Sonny's Barbeque)
Specification/Design document is due.
Week #7 – Guest Lecture #2 (Sealund and Associates)
Week #8 – Project Work Day
Open lab day for project work (in class). Will review prototype demonstration objectives and plans.
Week #9 – Guest lecture #3 (Sypris Electronics)
Prototype demo is due. You will need to schedule a 30-minute time slot outside of the regular class time.
Week #10 – Guest lecture #6 (TBD)
Test plan is due.
Week #11 – Guest lecture #5 (CAE Corporation)
Week #12 – Exam week
Mid-term exam in class (exam covers lectures and textbook).
Week #13 – Demo week
Project demo is due. You will need to schedule a 30-minute demonstration time slot.
Week #14 – Guest lecture #4 (Harris Corporation)
Week #15 – Final presentations and demonstrations
Final presentation and demonstration at the corporate site need to be completed this week. The final project documentation and artifact including a poster and press release is due.

APPENDIX B – COURSE DELIVERABLES

This appendix contains the course deliverables from Fall semester 2002. This was a 14 week semester. For each deliverable, the percentage of overall course grade and the week in which it is due are shown. The final 10% of the overall course grade comes from the mid-term exam (week #12) that covers the lecture and reading materials.

Requirements Document: (5% of grade – week #3)
Do you know what problem you are solving? Do you know what your customer wants? Can you describe to your customer, in your words, that you understand their need? You must clearly and crisply describe the project requirements. Requirements must be numbered so that they can be traced throughout the development project. Page limit is 2 pages.

Specification/Design Document: (5% of grade – week #6)
Do you know how to solve the problem and meet your requirements? This document should clearly specify the solution and include a design. A design could be a high-level flowchart or a hardware block diagram. The document must include details on the methods what will be used to solve the problem. The reader must be convinced that you have a workable and feasible design. Page limit is 2 pages (but appendices are allowed).

Prototype Demonstration: (20% of grade – week #9)
This is a major checkpoint. You must have something up and running. A prototype is something you can show your customer and ask, "Is this what you wanted?" The customer must be able to see that all features are in place (but, perhaps not fully working). For software, a prototype would include all interfaces.

Test Plan Document: (5% of grade – week #10)
How do you know you met the requirements (validation)? How do you know that you implemented your specification and design correctly (verification)? Describe your test cases for validation and verification. A test case must include requirement or specification number that is covered, procedure to execute, and expected results. Good test cases should cover expected and unexpected inputs. No page limit, but should be short.

Practice Presentation: (5% of grade – week #13)
This is a dry run of your presentation and demonstration. I need to see your overheads. Your presentation should not, in any case, exceed 30 minutes. Expect lots of feedback and budget time to rework your presentation overheads for the final presentation.

Final Submission: (50% of grade – week #15)
Your final presentation and demonstration is given to your company supporter at the company site. You will deliver your final submission at this time. Your final submission should contain revised versions of all of the above documents, your presentation overheads, your artifact, and any final documentation that is required (e.g., user documentation if a software product, complete specifications if a hardware product). Your final submission also includes a poster and a press release.

- Poster – The poster is a self-explaining presentation of your project. The poster will be hung in ENB 313 (or ENB 337) for at least one semester. The organization of a poster will be discussed in lecture.
- Press release – The press release is a one-page project description suitable for the general public. Unlike the other deliverables, the press release may be somewhat self-promoting. The writing of a press release will be discussed in lecture.