AC 2012-3862: TREND ANALYSIS OF CAPSTONE DESIGN PROJECTS FOR IMPROVING UNDERGRADUATE ENGINEERING EDUCATION

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Trend Analysis of Capstone Projects for Improving Undergraduate Engineering Education

Abstract

Capstone design project is a major component of undergraduate engineering education. It provides an opportunity for the graduating students to combine several engineering principles and practices into a functional prototype in order to meet some customer requirements or to solve a technical challenge. In order to enhance the capstone design experience of the students, it is necessary to analyze the projects carried out over a sufficiently long time. Projects can be analyzed based on several criteria. Examples could be its source of sponsorship, technology being used in the project, and its field of application. Also, such an analysis needs to look at the preparatory ingredients of the curriculum in the lower level that led to the capstone design project. A mini project in a course can be an important contributor for a capstone design project. A mini project is one that combines several concepts/topics within that course into a small design or implementation unit. Usually a mini project spans over a few weeks and includes a report and/or presentation on a topic chosen either by the instructor or by students. A respectable credit is assigned for such a mini project within a course. A curriculum that contains several courses with mini projects in earlier years of education would help students prepare well for the capstone design project. If these mini projects of different courses are designed coherently, the experience gained by the students is significant. As such, the mini projects undertaken by the students in a curriculum need careful consideration in order to have relevance and impact on the capstone design project. This paper attempts a study and an analysis of the mini projects as well as capstone design projects carried out at Electronics and Telecommunications engineering program of a University. This analysis found out strong industry sponsorship of capstone projects (more than half) as strength that need to be maintained as well as a few shortcomings that need to be overcome. It also revealed correlation between the trend of mini projects and capstone design projects in the curriculum.

I. Introduction

Importance of capstone projects have been extensively highlighted in literature [1][2]. Capstone projects allow a group of graduating students to combine several concepts into a functional prototype that solve a technical challenge or meet some customer requirements [3]. It enables students to view project in its totality rather than in isolation. Students learn to understand a problem, think about possible technical solutions, their complexities and cost associated with each solution, choosing a solution with trade-off between competing demands. They also go through the process of implementing the project, testing the project to meet some specifications, and documenting the project for ease of understanding as well as further improvement. As such, the capstone project provides a complete engineering experience for the graduating students which they can readily apply in their career.

It is expected that the students, in carrying out the capstone project, follow some proven steps in a systematic and timely manner. They need to plan ahead for each of the tasks and allocate appropriate amount of time for each. They often need to set some milestones and check their progress against them. This way they can remain on-track for completion of the project.

Even following the above steps, the outcome of the project may vary from what was originally intended for due to some reasons or other. This variation may be favorable or otherwise. As such, there is always a need for analysis that identifies any specific strength or weakness as well as factors that are beyond control. This leads to formulate more specific guidelines and requirements that will ensure more predictable outcome of the project.

An atypical capstone project has been presented in [3]. Instead of a working prototype, it shows that clearly defined design and development process resulting in project deliverables has accomplished the learning objectives of a technical capstone project. It has been suggested that an investigation of previous course projects leading to capstone work is important [4]. It would reveal what aspects of required proficiency have been addressed in the preparatory courses. This investigation would also find out at what level they are addressed. It is suggested that the project activities that support humanitarian needs facilitate the motivation to complete a successful project with strong sense of teamwork [5]. However, these works did not attempt to connect course projects to capstone projects.

In this paper, several course related mini-projects as well as capstone design projects are analyzed. Subsequently, a correlation between them is investigated and good practices are highlighted. Additional suggestions are enlisted that are expected to enhance student's learning experience.

In section II, course related projects at different levels are discussed. In the following section (section III), trend of capstone design projects are analyzed. In section IV, correlation between course projects and capstone projects are highlighted and some suggestions are enlisted for enhancing student experience in such undertakings. The paper ends with a conclusion.

II. Mini Course Projects

The following enlisted courses include at least one course-project on a topic chosen either by the instructor or by students. Some courses could not be surveyed due to unavailability of the faculty member. A brief description of various aspects of these projects is included in this section.

Circuit Analysis I (ENTC 210): In this course on circuit analysis, there is a course project that carries a bonus point of 3% weight of the course. Typically 2 students form a group to work on the project for about 3 weeks outside their normal classes. It requires a formal presentation in the class.

Circuit Analysis II (ENTC 211): This course involves a team project that spans over the semester. Team consists of 3 to 4 members. It carries about 10% weight of the course. Students spend time for this project beyond scheduled hours. Although the project announcement is done at the beginning of the semester and is due at the end, the actual work needs about three weeks to finish.

Digital Electronics (ENTC 219): In this introductory course to Digital Logic, students design and implement hardware into an FPGA that controls a mobile platform. It is a team project consisting of two members. It spans over the last 4 weeks of formal laboratory time and carries a weight of 15% of the course.

Advanced Digital Circuits (ENTC 249): This course primarily involves digital system design using HDL (Hardware Description Language). A project involving design and implementation of an eight bit processor is undertaken. Typically, two students form a group and take about 6 weeks of laboratory time to complete this project. This project carries 6% weight of the course.

Local/Metropolitan Area Network (ENTC 315): This is a course on local area networks. It has a project that is declared at the beginning of the semester. It is carried out in a group of 3 students and bears a weight of 10% of the course. Apart from the time spent beyond the formal classes, the last three weeks of laboratory time is devoted to this project.

Wireless Communication (ENTC 345): This course covers wireless communication and consists of three simulation based projects. Each project carries about 10% weight of the course. These projects are individual and each lasts for about 4 weeks.

Analog Electronics (ENTC 350): This course has one project that spans for 8-weeks. Project consists of identifying an electronic kit that involves major electronic building blocks such as op-amps, diodes etcetera. It involves a presentation explaining operation and testing. This is an individual project and carried out beyond the class or laboratory hours. It carries about 13% weight of the course.

Introduction to Mixed Signal Test (ENTC 352): This course entails mixed signal testing and involves a project of developing a test plan. The project spreads over 7 weeks with 2 to 4 students in each group. It carries a significant weight of 50% of the course.

Electromagnetics and High Frequency (ENTC 355): In this course there are two mini projects involving fabrication of microstrip antenna. Each project lasts for about 2-3 weeks of laboratory time. It is conducted in a group of 3 students. These projects carry about 6% weight of the course.

Electronics System Interfacing (ENTC 359): This course has one project that spans for 7-weeks. A group consisting of 3 to 4 students uses the formal laboratory time over the duration of the project. It carries a significant weight of 20% of the course.

Data Communications (ENTC 435): In this senior course, students carry out two different projects related to data communication. They spend about 7-weeks of formal laboratory time for each. Project is carried out in a group of 2 and carries a significant total weight of 25% of the course. There are no other formal laboratory exercises in this course.

From the above discussion, we can draw certain conclusions.

- Majority of the courses have projects
- Most of them involve implementation of a given idea rather than design
- Majority of them are group projects

- Weight varies (from 3% to 50%), duration varies (from 3 week to 7 week)
- Project evaluation mainly involves explanation of the functionality rather than motivation behind undertaking of the project.

As a whole, presence of significant number of course projects is healthy. It teaches many aspects of engineering practice in a team environment. Course projects are evaluated in different forms such as a formal report, oral explanation, presentation, demonstration etc. However, the course projects need to address the issue of independent problem solving skill as well as some aspects of design.

III. Trend Analysis of Capstone Projects

In this section, some observed trends of the capstone projects have been presented and discussed. The projects were carried out between 2005 and 2010 [6]. A total of 65 projects were examined that involved 221 students and direct involvement of 9 faculty members. The published documents for each project were studied to obtain the following information: motivation behind the project and beneficiaries of such project, industry sponsorship of the project, use of technology, and reference citing in the report.

Number of Projects: Table 1 enlists the capstone projects carried out by graduating students from 2005 to 2010. It shows that an average of 11 projects is undertaken by the students each year. This number varies from year to year owing to many reasons such as student enrollment, number of students reaching the final year, as well as the number of students in a team (scope of the project). This also reveals that each project team has about 3.4 members. Considering the typical tasks involved in an engineering project (hardware, software, integration / test, project management), this number ensures fair distribution of the workload among the team members. This also highlights that each faculty member, on an average, had to supervise more than 7 projects per year. This needs to be justified considering other faculty responsibilities like teaching, research, and service.

Table 1. Number of Projects in Each Semester

2005		2006		2007		2008		2009		2010	
Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
8	11	5	8	3	6	4	5	2	5	4	4

Explanation and Quantization of Motivation:

Before embarking on a project, it is important to identify a problem that has respectable significance. This justifies undertaking of such project with appropriate motivation [5]. In order to assess the significance of the problem, it is necessary to quantify its current state and the effects the project will have after completion. This can be done by measuring current quantities such as power or space requirements (for example) and relating them to a constrained budget. With this scenario, the project could be formulated with a motivating target of reducing those quantities to meet the constraints. This process of quantization is of prominence for the students as they can visualize the benefits the project has the potential to bring into. This needs to be an integral process of formulating a project. Based on the analysis of the sample that we have chosen, this process of explanation and quantization has steadily increased through the years 2005 to 2008 as depicted in Figure 1. However, a decline is noticed since then. A probable reason could be that this has not been highlighted as an important element of the project. Students might have felt that the explanation of correct functionality of a project is more important than quantizing its benefits. The last concluded point stated in the previous section could be the reason why justification for undertaking capstone project is not highlighted in the final capstone report.

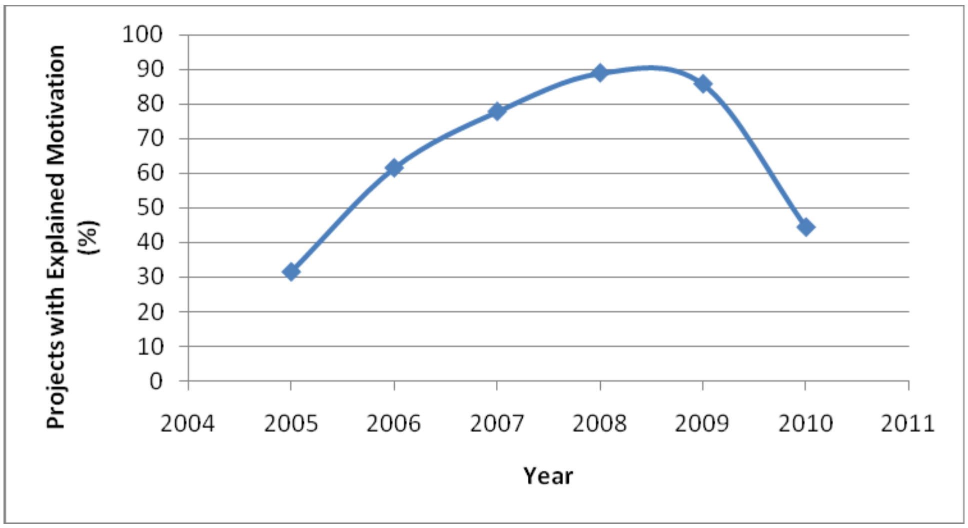

Figure 1. Percentage of Projects with Motivation Explained

Industry Sponsorships:

It is good to have industry sponsored projects as this relates to real world projects. With such projects, students are mentored not only by faculty but also by practicing engineers. The experience gained by students through such project becomes invaluable in their future career. Figure 2 shows that more than 50% projects are industry sponsored (33 out of 65). This is healthy and needs to be upheld. However, care must be taken to choose such projects in order to maintain academic standard. It is expected that the industry sponsored projects incorporate some innovation. This extends students imagination out of the box.

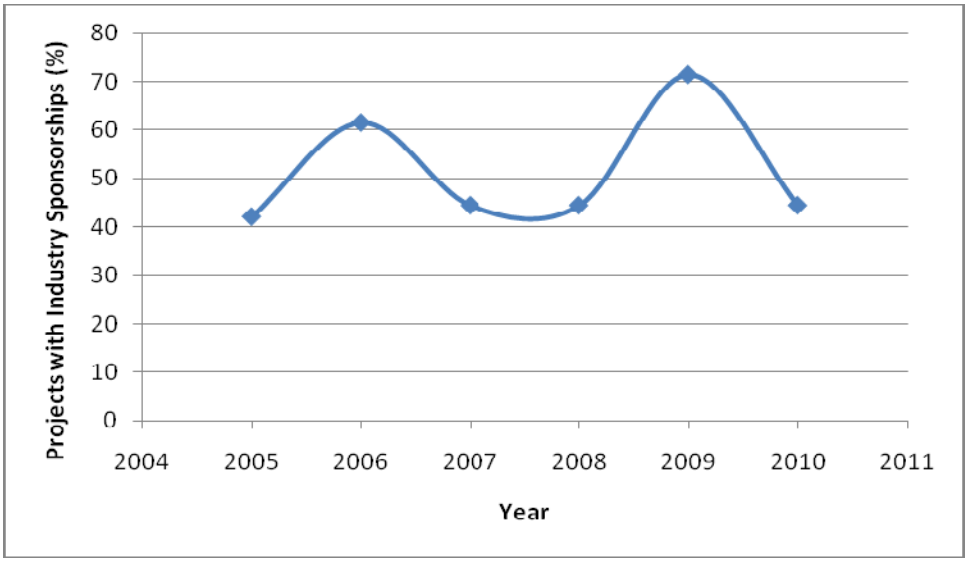

Figure 2. Industry Sponsored Projects

Microprocessor / Microcontroller usage:

Use of microprocessor or microcontroller has penetrated all fields especially the embedded domain. As majority of capstone project falls into the embedded category, such penetration is obvious and is reflected in Figure 3.

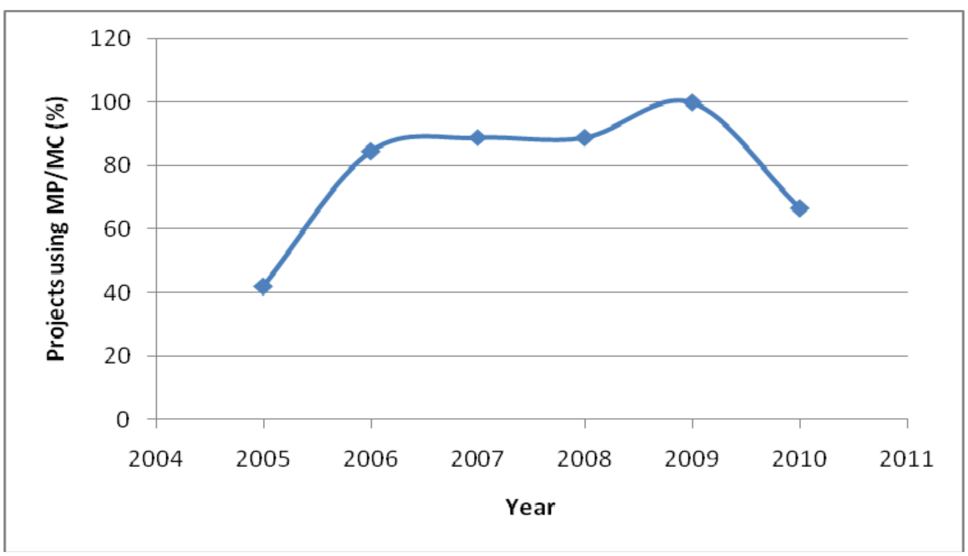

Figure 3. Percentage of Projects using MP/MC

With gradual increase from 2005, the usage level has reached 100% in recent years. This is healthy as use of microprocessor provides flexibility to the system by adjusting / modifying the code to suit the changing requirements. However, for each project a justification is necessary for such a use. Because a system with programmable processor usually consumes more power than a dedicated hardware, only such justification would satisfy all the stake holders of the project. On the other hand, the use of other programmable devices such as Digital Signal Processors (DSPs) or Field Programmable Gate Arrays (FPGAs) are almost insignificant in the sampled projects. This is reflected in Table 2 where Programmable Component (PC) includes devices such as Digital Signal Processors (DSP), Field Programmable Gate Arrays (FPGA). The reason for not using PC may be that the students are not exposed to such devices. However, this is expected to change as there is an initiative to change the curriculum with emphasis on usage of FPGAs for hardware design.

Table 2. Other Programmable Component (PC) usage in Capstone Projects

2005		2006		2007		2008		2009		2010	
Total Projects	PC usage	Total Projects	PC usage	Total Projects	PC usage	Total Projects	PC usage	Total Projects	PC usage	Total Projects	PC usage
19	2	13	1	9	0	9	0	7	0	9	1

Project Reports with Reference Section:

Good project report needs to include references. Cited references prove that existing literature was surveyed in order to appreciate what was done before [7]. This also ensures any novelty included in the project is well justified based on the previous work. A reference section, to some extent, authenticates and justifies the work done in a project. Unfortunately, none of the 65 project reports contained a reference section as shown in Table 6. This is a major point that needs to be emphasized and incorporated in all future reports. Capstone projects are evaluated through a series of submitted documents, formal presentations, as well as demonstration.

Table 6. Reports with Reference / Bibliography Section

2005		2006		2007		2008		2009		2010	
Projects	Includes references	Projects	Includes references	Projects	Includes references	Projects	Includes references	Projects	Includes references	Projects	Includes references
19	0	13	2	9	0	9	0	7	0	9	0

IV. Correlations and Suggested Improvement

From the above discussions, we can see that the course projects carried out by the students in preparatory years have enabled them to undertake more challenging real-life capstone projects. About 50% of the capstone projects were industry sponsored. Students were able to complete them with reasonable success. Moreover, they have mastered well the microprocessor usage in projects. About 77% of the surveyed projects used them. This is due to the involvement of microprocessors in ENTC 249, ENTC 349, ENTC 359, and ENTC 369 courses for the course projects. However, they have not used other programmable devices such as DSPs, FPGAs, or Network / Graphic processors in the projects. It is due to a lack of that emphasis in preparatory courses. In addition to this, we observe a lack of well explained motivation of the capstone projects. About 65% reports include them in some form. This happens due to the fact that the students mainly carry out course projects given to them by the instructors. They usually do not carry out a literature search to find out one that motivates them. As a result of this phenomenon, they also do not have a reference section in their capstone report.

The students need to assess the impact of the project and quantize it when possible. This may include such metrics as how many persons will benefit from this project, how much energy or time savings it will result into etc. This will enable them to clearly relate their work to some proposed value. They also need to critically think about different alternatives of project implementation. While implementing, students need to pay heed to creating non-traditional customized components instead of using off-the shelf components. Field Programmable Gate Array (FPGA) could benefit in this respect of creating custom components. With FPGA, simulation of cascaded components is possible while the same is not possible for system built with off-the-shelf components from different vendors. Final project report with a list of references would definitely add much credential to projects.

V. Conclusions

Capstone project is a major component of engineering education that integrates and reflects knowledge gained in preparatory years. In this paper, the existing course projects in Electronics and Telecommunication program of a university were examined. The capstone projects carried out over a sufficiently long time by the same students who went through these course projects were also analyzed. Some correlations between them were identified. Strengths of the course projects and capstone projects were highlighted as well as improvements were suggested.

Acknowledgment

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