Capstone Design in the ECE Curriculum: Assessing the Quality
of Undergraduate Projects at WPI

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Abstract

Since adopting the WPI-Plan in 1972 at Worcester Polytechnic Institute, one of the degree requirements for undergraduates has been the completion of a Major Qualifying Project. Although this project significantly predates the current ABET requirement for providing students a capstone design experience, as implemented within the Department of Electrical and Computer Engineering, it captures both the spirit and letter of this requirement. The objective of this paper is to provide a brief description of the Major Qualifying Project at WPI and to provide some quantitative data showing the effect of the MQP on Electrical Engineering students over a six year period.

Introduction

As originally conceived, the Major Qualifying Project, or MQP, was intended to provide students with a final project to link their academic experiences to their future career as engineers. Today, this project manifests itself as a serious, year-long effort to complete an engineering project quite similar in nature to the type of project a student might be assigned as an entry-level engineer. Within the context of this project, students have designed, built, and tested electronic systems to perform sophisticated signal and image processing, to evaluate computer network performance, to measure water flow in the canals in Venice, and even to develop experiments which were carried on the Space Shuttle. Given the nature of an MQP, it provides a unique opportunity for students to complete serious projects that apply current technology to solve real engineering problems.

Perhaps even more importantly, the MQP provides an ideal mechanism for fulfilling the ABET-required capstone design component of an undergraduate's education. Since most real engineering problems often start as loosely specified ideas, successfully completing an MQP requires that students develop design specifications, evolve efficient designs, evaluate their designs relative to performance specifications and human factors, and finally implement, test, and document their designs. These activities directly address both the spirit and the letter of the ABET capstone design description.

This year, the ECE department completed its third biennial review of the MQP process. During this review over 60 project reports from more than 100 senior undergraduates were evaluated based on a wide variety of criteria, most of which directly overlap the ABET capstone design definition. As a result of this review, we found that the goals of the MQP were satisfied by the vast majority of projects. In addition, we found dramatic shifts in the types of areas that students were addressing in their projects which, we believe, is a direct consequence of major curriculum overhaul in the ECE department over the past few years. This paper will put these results in a context that will allow other ECE departments to benefit from the experience we have gained at WPI.

What Is An MQP?

The WPI Undergraduate Catalog states the following:

> *"The Major Qualifying Project should demonstrate application of the skills, methods and knowledge of the discipline to the solution of a problem which would be representative of the type to be encountered in one's career. The project's content area should be carefully selected to complement your total educational program.*
>
> *MQP activities range through research, development and application, can involve analysis or synthesis, can be experimental or theoretical, and can emphasize a particular subarea of the major or combined aspects of several subareas. Serious thought should be given to which of these types of activities are to be included."*

A quick review of the ABET criteria for Capstone Design yields the following definition:

> *"Each educational program must include a meaningful, major engineering design experience that builds upon the fundamental concepts of mathematics, basic science, the humanities and social sciences, engineering topics, and communication skills. The scope of the design experience within a program should match the requirements of practice within that discipline. . . . . A meaningful, major design experience means that, at some point when the student's academic development is nearly complete, there should be a design experience that both focuses the student's attention on professional practice and is drawn from past course work . . . . "Meaningful" implies that the design experience is significant within the student's major and that it draws upon previous course work, but not necessarily upon every course taken by the student."*

It requires little imagination to see how closely these definitions are aligned in spirit. However, the ABET definition is considerably more specific about the types of activities that must take place. Although the vast majority of projects done within the Electrical and Computer Engineering Department satisfy the ABET criteria, it is possible that a perfectly appropriate MQP may not be an adequate Capstone Design experience. Since such cases are in the minority, they are handled on an individual basis to ensure that all students complete both an MQP and a Capstone Design experience.

The MQP Process

Unlike a course, an MQP is typically performed by a team consisting of an advisor and one to three students, with teams of two students being the most common. Each project typically spans a full academic year and an individual advisor will typically be involved with several different project teams each year.

Within an MQP team, the role of the advisor is much more that of a senior-level engineer mentoring more junior engineers rather than a conventional professor/student relationship. In this relationship, students are expected to be proactive in all phases of a project. Unlike a typical course, where the students are given assignments related to lecture material, in an MQP the students are responsible for determining what must be done, what problems must be solved, and how to solve them. Like a senior engineer, the advisor may give guidance to students to ensure that they follow a rational trajectory, but does not "teach" the students how to solve their problems in the conventional sense.

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[1] Criteria for Accrediting Engineering Programs in the United States, for evaluations during the 1993-94 Accreditation Cycle, Engineering Accreditation Commission, New York, NY, page 7.

The process students follow is quite similar to the process they will see as entry-level engineers. Most projects go through five basic phases: project definition, research, design, evaluation, and documentation.

Project Definition

During the project definition phase, the students must determine exactly what their project will be. It may start with a suggestion from a potential project advisor, an idea created by the student, or a request from local industry. Since the initial idea typically is incompletely specified, the students must identify missing details and perform any high-level engineering necessary to forma complete detailed project specification. This phase of an MQP usually results in the delivery of a short paper detailing the project goals, projected schedules and budgets, and the methodology needed to satisfy the project objectives.

Research

During the research phase the project definition is refined into a detailed specification. Often, a project will require the student to gain information or skills that were not covered in their coursework. As a result, the students must teach themselves the skills necessary to verify that their specifications will result in a physically plausible project specification. The end result of this project phase is a 20-30 page report presenting the **block-**diagram level descriptions of each component in the system.

Design

Now that the team has a detailed description of each required component in the desired system, they may begin their design. During this phase, students make low-level decisions about how to best meet their higher-level specifications. Trade studies are an essential element in demonstrating to the project advisor that the team is considering all of the essential aspects of the system design. This ensures that designs are developed in a theoretically justifiable manner instead of being the result of making guesses followed by trial-and-error system debugging.

Evaluation

It is important that students learn to prove that that their designs are correct using simulation, theoretical analysis, and design reviews. During this phase, the advisor makes it clear, for example, that engineers cannot tell their manager that a new pacemaker design "should" work. Rather, they must demonstrate that it **does** work (and will continue working). Once the design is validated, it is constructed and tested relative to its specifications.

Reporting Results

The final phase of a project involves documenting the complete system in an MQP report and in a **conference-**style presentation to the students and faculty in the department. These reports are typically 100-150 pages in length and detail the entire system. The resulting documents are archived in the university library.

Biennial Review Process

To ensure that the objectives of the MQP are being satisfied, every two years the department establishes a committee to review MQP reports. This committee reads all of the reports generated the previous academic year and evaluates them relative to an established set of quality criteria. The last such review was conducted during the summer of 1995. Prior to this, reviews were conducted during the 1990-1991 and 1992-1993 academic years. During the 1995 review a total of sixty-two projects involving 108 students were evaluated.

The academic level—freshman, sophomore, junior, senior, and graduate level-of the electrical engineering, computer science and mathematics content of the projects was estimated from the related information presented in the project report. The vast majority of projects-98%—were found to contain ECE material at the junior

and senior levels. In fact, 74% were at the senior level and 2%-one project—was judged to be at the graduate level. These results are fully consistent with our expectations for MQPs.

This year, the ECE review committee evaluated the Computer Science content of MQPs for the first time. The range is broad with 14% judged to have little or no CS content while 48% were at the sophomore level, 36% at the junior and senior levels, and 2% at the graduate level. Considering that programming in C and Pascal along with the techniques of program design are at the 1000 level, with machine organization, computational paradigms, and algorithms at the 2000 level, these results appear reasonable, indicating clearly that computer science concepts form a significant component of ECE MQPs.

The mathematics content of MQPs continues to be broad as well. Ten percent were found to be at the freshman level while 58% were at the sophomore level, 27% at the junior level, and 7% at the senior level. The notable change from past years is the substantial increase in the usage of sophomore-level mathematics. Specifically, the usage of 2000-level techniques increased from levels of 27% and 20% in 1991 and 1993 respectively to 58%. Importantly, that shift was nearly exclusively a result of the decrease in MQPs with only freshman-level mathematics content from past levels of approximately 40% to the currently observed level of 8%. This result is consistent with the character of MQPs evaluated during this review; namely that, as a minimum, 92% not only employed calculus, but relied upon the methods of such topics as differential equations, linear algebra, and statistics-all 2000-level material-to achieve their objectives. This speaks positively to the fact that the sophistication and complexity of ECE MQPs has evolved in such a manner that the usage of mathematical concepts at the sophomore level and above have become essential.

The projects were also analyzed with respect to subareas within electrical and computer engineering. The two areas with the largest representation were analog electronics and computer engineering. Analog electronics formed a significant component in 37% of projects while computer engineering was manifest in 58% of projects. These results are quite different from those of the 1993 review where analog electronics, computer engineering, and signal analysis and communications were each represented in approximately 20% of the projects. In this regard, while there are significant differences between the results for the 1993 and 1995 reviews, it is also clear from the analysis of the data that the review committees used different criteria for making the subarea judgment. The current review committee focused on identifying all of the major subareas represented in each MQP while the prior review committee identified the principal subarea represented in each MQP. Consequently, the results obtained during the current review are consistent with what would be expected; specifically, that it is not surprising that the great majority of ECE MQPs contain significant analog electronic and computer engineering components. In a like manner, the areas of signal analysis and communications, controls and systems, power, electromagnetic, and software engineering were found to be well represented, appearing in between thirteen and 20 percent of the projects.

The presence of several specific components of the engineering process was also reviewed. These are: measurement and analysis, hardware design and construction, software design and implementation, computer simulation, and the use of other computer devices such as embedded microprocessors. With the sole exception of "other computer usage", all of these engineering process components were found to be well represented with at least 40% of the projects having accomplished "much" or "very much" work on each of the components identified above. Other computer usage was found to be at a comparative level of 24%, down from the 40% level observed during the 1993 review. On the surface, since the availability of an ever widening spectrum of computer components continues to improve, this condition appears to be counter intuitive—especially since nearly sixty percent of projects were found to have a significant computer engineering element. Because the definition of what constitutes other computer usage is not well defined, it is reasonable to expect such differences. To better correlate the 1995 results with future reviews, the quality criteria used to evaluate the reports have been refined.

Two additional observations on engineering process components are appropriate. First, it is encouraging to note that sixty percent of project teams-up from the 45% level observed during the 1993 review—accomplish "much" or "very much" measurement and analysis as part of their MQP activity. Second, it is also encouraging to note that the percentage of projects containing no hardware design or construction has decreased from the

40% level observed during the 1993 review to 21%. This is probably due, in part, to student reaction to the "capstone design" requirement which demands an additional design experience for MQPs that are primarily analytical in nature.

Conclusions

The following is a summary of the major conclusions of the review committee:

- The overall educational goals of the MQP are being met.

- The design content of projects is high—as it should be—and is consistent with capstone-design expectations.

- While most MQP reports address "non-design" factors such as: economics, safety, reliability, aesthetics, ethics, and social impact, their level of emphasis is lower than desired. Additional faculty attention must be directed towards increasing student perception of the importance of these factors.

- Documentation quality is generally quite high.

The overall quality of ECE department MQPs has been found to be quite high and we find no question of the continued educational value of this degree requirement. We also find that the MQP provides an excellent vehicle for providing a meaningful capstone design experience for the students.

The range of topics along with the exceptional quality observed in many of them and the extent of external interest and sponsorship experienced is truly impressive. Even so, it is important to continue looking for areas where the MQP process should be modified or emphasized to further enhance the value of the MQPs contribution to the overall educational experience.

The overall conclusion of the review committee is that the MQP process and the projects themselves are fundamentally sound and are meeting educational objectives in all respects.

Biographic Information

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Dr. Michalson earned his Ph.D. degree in electrical engineering from Worcester Polytechnic Institute in 1989. In 1981 he joined the Raytheon's Equipment Division where he was involved in the development of real-time, fault-tolerant computer systems for military applications. Since joining the WPI faculty in 1991, he has been heavily involved with research targeted at civil applications of the Global Positioning System.

ROBERT LABONTÉ

Robert Laborite' received his B.S and M.S. degrees in electrical engineering from Worcester Polytechnic Institute in 1954 and 1959 respectively. Prior to joining the WPI faculty in 1993, he worked at MITRE Corporation where he was involved with a variety of research and development projects related to special-purpose surveillance and control systems. He is currently the Director of WPI's space experimentation program.