

CAPSTONE DESIGN AT WPI

An Evolution of Projects Based Education

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ABSTRACT

Since 1971, all students at WPI have had to complete two major projects as part of their graduation requirements. The first, known as the Interactive Qualifying Project, “*relates technology and science to society or human needs. This project ... challenges students to relate social needs or concerns to specific issues raised by technological developments*”¹. Currently, more than half of all WPI undergraduates complete this project as part of a “project center”, the majority of which are in international locations. The second project “*is a project in the major field of study ... called the Major Qualifying Project, or MQP. This project should focus on the synthesis of all previous study to solve problems or perform tasks in the major field with confidence, and communicate the results effectively*”¹. The MQP satisfies the ABET capstone design requirement² and is fundamentally different from a course based capstone experience. As might be expected, our implementation of the WPI vision for projects based education, and in particular our fourth-year capstone project has changed in several fundamental ways since inception. Among these changes have been the development of industry based “project centers”, the development of global project opportunities, on and off-campus opportunities to complete the project as part of interdisciplinary teams focusing on specific technologies or issues, and on-campus interdisciplinary project opportunities that have a specific national program focus (e.g. development of a small satellite or taking part in a national autonomous vehicle design competition). In this paper we present an overview of our approach to the capstone project requirement and describe how our capstone projects have adapted to changing educational needs, globalization and student interests. Finally, we will also describe how we assess and continuously improve our projects and the WPI projects program.

Introduction

The purpose of this paper is to describe the WPI senior capstone project requirement known as the Major Qualifying Project, or simply **MQP**. This focus would not be complete, however, without a brief description of how this senior year project fits into the framework of the general projects based education of the WPI curriculum¹.

WPI

Founded in 1865, WPI is primarily a private technology-oriented university, located in Worcester, Massachusetts, about 65 km west of Boston, with over 2700 undergraduate students, ~800 graduate students, and 230 fulltime faculty. WPI was recently named by the Association of American Colleges and Universities as one of 16 "Leadership Institutions" for excellence and innovation in undergraduate education³. WPI students pursue degree programs (BS, MS, and PhD) primarily in engineering, the sciences and management.

WPI Curriculum

As stated on the WPI web pages⁴.

"The goals of the undergraduate program are to [...] form a deep appreciation of the interrelationships among basic knowledge, technological advance, and human need. *These principles are today manifest in **the WPI Plan**, a unique, **project-oriented program** which emphasizes intensive learning experiences and direct application of knowledge* [italics and bold added].

The WPI Plan^{5,7} includes two components that are pertinent to this presentation.

- **Four, 7-week terms** (excluding summer) to accommodate short, intensive courses of study including traditional courses and laboratories, on- and off-campus projects, internship and coop programs, study abroad and other types of educational endeavors.
- Degree requirements⁶ based on, among other provisions, completing **two major defining projects**.

Major Defining Projects

All WPI students are required to complete two major projects⁸ (**bold** and *italics* added below).

- **"A project which relates technology and science to society or human needs.** This project, known as the **Interactive Qualifying Project**, or **IQP**, should challenge students to *relate social needs or concerns to specific issues raised by technological developments.*"
- **"A project in the major field of study.** Called the **Major Qualifying Project**, or **MQP**, this project should *focus on the synthesis of all previous study to solve problems or perform tasks in the major field with confidence, and communicate the results effectively.*"

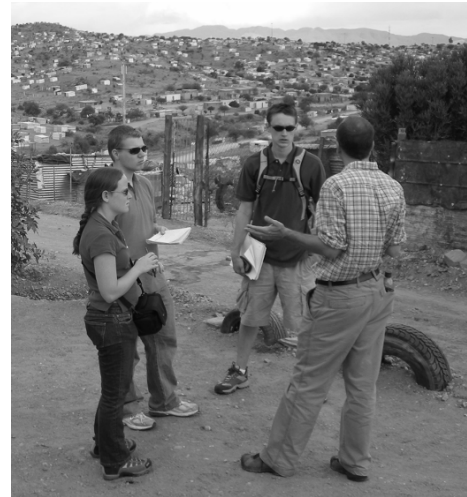
The IQP - Unique in the World of Engineering Education⁹

The IQP is *not* directly related to a student's major areas of study. Instead, by working on multidisciplinary teams to address problems related to technology, society, and human needs, students come to understand how their careers will impact, and be affected by, societal structures and values. A central learning outcome of this project is an understanding of the social and cultural contexts of technology and science. The students are presented with an *open-ended* problem statement and are expected to develop specific goals, conduct research, gather relevant information, and provide a useful result to the project sponsor. The IQP is an academic degree requirement equivalent in credit to 9 credit hours. It is important to understand the concept of the IQP since it serves as part of the *framework* for understanding the structure and implementation of our capstone project requirement, particularly since it is typically completed in the third year of study, prior to starting the senior capstone project. More information on the IQP can be found on the WPI web pages⁸.

Project Centers

To support the globalization of the IQP, WPI has created a network of **Project Centers** within the context of the Global Perspective Program¹⁰. These centers including programs in Europe, Central America, North America, Africa and the Asia-Pacific region. Efforts are currently underway to develop centers in China, India and other locations as opportunities arise.

Typically, ~24 students and 2 faculty advisors spend one-term on-campus in preparation (3 credits) for work at one of the centers. Subsequently, the faculty advisors along with the students move to the center location and live and work fulltime (9 credits) for an additional term, and usually a week or two longer (infringing into the break between terms) on their projects. Students generally work closely with community organizations and interact with community members in an academic undertaking that will benefit the local population while allowing the students rich opportunities to learn from the community and to reflect on that learning. At the conclusion of the project, the students develop a comprehensive formal written report of their research and findings and present their work orally to the sponsoring organization. Approximately 60% of all WPI students complete their IQP at an off-campus project center.



WPI project students with faculty advisors (Krueger, Looft) on location in the Havana informal settlement (Windhoek, Namibia, March 2007).

Take home thoughts from the WPI Projects Center organization and IQP include the following.

- The IQP is *unique* in the world of engineering and very different from traditional "student abroad" programs in that there is no on-site course activity, no association with a local university (perhaps other than housing), and no class room based education.
- Projects are *sponsored* by local for- and not-for-profit agencies, government organizations and NGOs. Further, the projects are considered professional level and are carried out on behalf of an organization seeking information and/or help in solving a problem.
- Students work in *interdisciplinary* teams on interdisciplinary projects.
- The projects themselves are *required*, in some way, to relate technology and society.

The MQP¹¹

In this section we describe the generic WPI capstone project requirement known as the MQP. We then describe the MQP program from the ECE perspective - focusing on topics such as the development of ECE/WPI project centers, globalization, assessment and so forth.

Briefly, the senior capstone project encompasses the following components similar to the IQP described above.

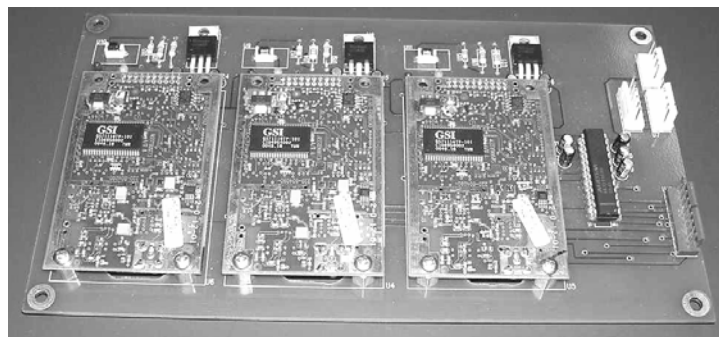
- *Required* of all students in *all* majors (not just ABET accredited departments).
- Three course equivalent (*9 credit hours*).
- *Not course based*. Based on weekly meetings (and usually more frequently) between the project advisor and students over the course of (typically) a full academic year.
- *Teams* with ~2-4 students per project, often more if interdisciplinary in nature (an attempt is usually made to have at least two students in each major, but this is not a requirement).
- Comprehensive required *detailed project report*.
- Required *oral presentation* during campus-wide “**project presentation day**” (classes are cancelled).

Typical Project

A representative recent project is described here to provide an understanding of the breadth and depth of a typical capstone project.

Multi-GPS Based Orientation System (3 ECE students) - The students on this project developed a multi-GPS based system to determine the orientation of a small-sat based on phase relationship between received GPS signals. Project activities included the following.

- Develop a system design specification including all interface and operational requirements.
- Model the complete system using Matlab, accounting for the very short baseline (18”) antenna separation, Doppler shift due to satellite orbital velocity, location and viewing angles of GPS satellites and so forth.
- Use the model to verify system operation and, where necessary, modify the system design to be able to meet the desired performance specifications.
- Develop (and learn about) Kalman filters for processing phase measurements to achieve the required phase accuracy. Implement (Matlab) the selected Kalman filter(s) compare system resolution and performance.
- Select components and design circuits and systems to meet system specifications.
- Prototype and test.
- Design final PCB layout. Build and test.
- Compare system performance to specifications.
- Thoroughly document project designs, specifications, analyses, trade studies and results.
- Complete final oral presentation.



Multi GPS Receiver Satellite System Prototype

The students on this project were part of a much larger multi-disciplinary team that met once a week to discuss progress toward goals, program successes and problems, and how the results from some of the projects (e.g. power dissipation) would impact the work of other teams (e.g. thermal).

The ECE Capstone Implementation

There are three significant differences between the ECE implementation of the capstone (MQP) project compared to most other departments at WPI. These include **i**) the implementation of a pre-project preparation course, **ii**) the development of very successful corporate based project centers, and **iii**) the use of existing (IQP) project centers to foster the development of global capstone project opportunities.

Capstone Preparation Course

A critical question discussed at a recent ECE Department Head Association (ECEDHA) regional meeting was “Where exactly do students learn how to do a project?”. Clearly, students learn *some* of the skills necessary to successfully complete a capstone project through their previous courses, but likely *not in the structured manner desired*. Although some project and team work skills are acquired by WPI students during completion of their IQP, the ECE department decided that there were significant advantages to *directly* addressing project skill-set development in a *technical* environment.

As a result, about eight years ago we created a late-second/early-third year course called ECE 2799 - Electrical and Computer Engineering Design. According to our course outcomes, students who successfully complete this course should be able to:

1. Demonstrate knowledge of the steps involved with the system design process.
2. Demonstrate the ability to apply engineering design steps to the decomposition, solution, and implementation of an unbounded design problem.
3. Demonstrate an understanding of the organizational issues associated with engineering design.
4. Demonstrate an understanding of the relevance of ethics, reliability, safety, and regulatory issues in the design process.
5. Demonstrate a working knowledge of the financial, schedule, legal, and other administrative elements in the design process.
6. Demonstrate the ability to effectively use written communications to report project status and results.
7. Demonstrate the ability to use oral communications to report program status and results.

The course itself is based on a **project**, much like that of the capstone experience but at a lower complexity level (e.g. design an electronic read-out for a torque wrench). Students are assigned to small teams of ~4 students. There are four lectures a week, 24/7 open project lab periods, smaller recitation sections, and several types of paid tutoring help available for the duration of the course. Students are required to successfully complete this course prior to starting their capstone project.

A benefit of offering this course early in the undergraduate ECE curriculum is that students learn early on the *value* of applying “knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints” (ABET). We specifically pick projects that require rigorous application of

basic principles and allow us to incorporate, by example, topics we believe are *critical* to the development of students who are prepared to work their capstone.

Annual ECE senior survey data shows that students repeatedly cite this course as the basis for their successful completion of their capstone project, for knowing how to define and solve vague open ended problems and for being able to work effectively on teams.

Capstone Project Centers - An Industrial and Global Focus.

Traditionally, projects are proposed by faculty (often linked to research interests), students, or industrial colleagues. The projects are then completed over the course of an academic year with the student project team members and faculty advisor(s) meeting at least once a week to review progress, critique designs and so forth.

Perhaps the most significant change in how we implement the senior capstone project experience has been the development of the **industrial project center**. For the past several years, about 40-60 ECE seniors (typical senior class size of 100) have completed their project requirement as part of an industrial on- or off-campus industrial project center. An example of an industrial project center follows.

Lincoln Laboratories Project Center

Approximately 16-18 students a year (predominately ECE) complete their MQP at Lincoln Labs (LL). The students apply in their junior year, are interviewed and selected to specific projects proposed by the professional staff mentors at LL. Originally, as with all of our project centers, we required our LL students to complete a preparation course the term prior to working full time on-site. Since the on-site term is the first term of their senior year, nearly all students now complete a paid summer internship at LL and no preparation course is required as a result. When the fall term starts, they register for 9 project credits (no pay) - generally working on a different aspect of the same summer project. The advantage of this approach is that the students are able to work at a very high level on a more complex problem than might be reasonably expected if the students were work with no preparation for 8 weeks, full time, on their selected problem.

Once the academic year projects start, LL provides daily transportation to/from LL. The students are advised on-site by their project mentor(s) on nearly a daily basis, and on a weekly basis by their WPI advisor who insures the academic quality, quantity and comprehensiveness of the projects.

The clear advantages of these centers can be summarized as follows.

- Cost and time effective to the students. Students complete their project in one-term of very intense (9 credit) on-site work as opposed to three, or four terms of on-campus work (2-3 credits per term).
- Project work is preceded by an internship or preparation course where the students perform the background research necessary to understand their specific project.
- As with the IQPs, the selected projects are not make work, but represent real world experience and problems with real engineering, design and other constraints.

Going Global

Most recently, WPI departments and faculty have started merging IQP and MQP experiences where and when appropriate, or simply using the IQP global center as a base of operations for developing capstone projects. For example, the author has advised both IQPs and MQPs at the WPI London (England) and Venice (Italy) centers (and facilitated a civil engineering MQP on-site at the Namibia Project Center in March-April, 2007). For example, in Venice we have for many years studied the characteristics of canal boats in order to create data and perform analyses to determine exactly what types of boats and conditions result in the most damage to canal walls (an IQP). This has recently led to funding for the development of GPS based electronic instrumentation systems that, once mounted on a boat, automatically estimate the magnitude of turbulence generated in the water by the boat (an MQP).

Other opportunities are being explored by other ABET and non-ABET accredited departments to merge and capitalize on the project center concept. Thus, although project centers were originally created to address a desire to offer global educational opportunities to our third year students, they are now being used both directly as capstone project implementation sites, and indirectly as models for developing similar centers for our fourth year capstone projects.

Capstone Project Assessment

At the conclusion of each capstone project ECE faculty advisors are asked to complete a brief and simple survey which asks for the advisor's evaluation of the achievement of every project *student* in two general categories. Representative items for each category are listed below.

- **Program Outcomes**
 - Appropriate Use of Math/Science/Engineering Knowledge
 - Design of Experiments/ Data Analysis
 - Functioning Multidisciplinary Team
 - Identify/Formulate/Solve Engineering Problem
 - Ability to Communicate Effectively
 - Need for Life-time Learning
- **Engineering Design**
 - Economic Considerations
 - Reliability Considerations
 - Aesthetic/Ethical/Social Impact
 - Analysis
 - Synthesis
 - Integration of Previous Course Work

In addition to the student data, a simple binary decision on whether the *project* demonstrates the indicated aspect or not is also collected. This approach for simple ranking of students and projects reflects the decision to keep the data collection process as simple and painless as possible for the faculty.

Additionally, every other year two ECE faculty members read every single project report completed in the previous two years. The idea is to have two “calibrated” readers assess every report for a range of factors including, for example, writing quality, quality of work completed for grade earned, level of design (e.g. representative of a fourth year engineering experience), level of mathematics, level of computer science, amount of analysis, use of modern tools (sw, hw, laboratory, etc), and numerous other factors. As stated in the introduction of the most recent review (2004-06) completed in January, 2007;

“During the review, a set of summary sheets were completed for each project. For consistency with prior year data, these sheets included the same two sheets that have been used in the department since the 1991 MQP review. In 2001, an additional WPI created sheet was filled out which was specific to assessing ABET-related criteria: Abet Criterion #3 and ABET Capstone Design. [. . .]

Wherever possible and meaningful, the results of this review have been compared to those that resulted from the previous ECE reviews. [...] We find no question regarding the continued educational value of this degree requirement. 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, an integral and significant component of this review has been to identify areas where the MQP process should be modified or emphasized to further enhance the value of the MQP's contribution to the overall educational experience.* (italics added)”

The report goes on to detail areas of strength and weakness, and areas in need of improvement. Although time and effort intensive, this biannual review is perhaps the most useful data generated in support of our review of the capstone experience.

Finally, every 2-3 years we also review our projects via an alumni survey and surveys of employers who hire our students. Clearly, these alumni and employer surveys also ask about other facets of our undergraduate educational program, but useful project evaluation data is gained as well.

Discussion

Over the past 35 years many of the factors and conditions that precipitated and then drove the development and implementation of the original WPI Plan have changed⁹. Yet, some components such as the project requirements, the highly interactive and team based learning environments, and regular and close interactions between the faculty and students have endured the test of time.

It is important to note that there are several aspects of the WPI educational program that make our approach to the capstone project possible, and perhaps not so possible at other universities and colleges. Chief among these are the following.

- WPI has four *seven week terms* in an academic year. We can accommodate short, intensive, off-campus project experiences up to ~9 weeks long, depending on the specific term offered.
- *All* WPI faculty are required to be involved in capstone project advising.

- Projects are worth *9-credits*. This is well beyond the spirit of the ABET requirement and allows students and faculty to undertake a much more intensive design project for the capstone experience.

Summary

It should be clear that the implementation of the capstone project requirement at WPI is significantly different than that of many other universities.

- Projects are not course based.
- There are a multitude of possible frameworks for completing a project both on- and off-campus. Students can complete their projects over the course of a full academic year or in a single term, and now can select from some (limited) global opportunities.
- Each department is free to develop their particular types of projects in the way that best suits their students. Many departments collaborate on interdisciplinary projects and centers.
- Project assessment is relatively easy to implement and provides meaningful data.
- The third year project experience serves as a solid foundation for developing teamwork, research, critical thinking and life skills needed by students to successfully complete their capstone project. Regardless, ECE has implemented a technical course to specifically teach students project related skills.
- WPI has nearly 25 years of global project center development. These centers are now being used as a mechanism for developing global MQP project opportunities.

References

1. <http://www.wpi.edu/Academics/Projects/>
2. ABET: 2006-2007 Criteria for Accrediting Engineering Programs
3. http://www.aacu.org/press_room/press_releases/2000/gxleadershippr.cfm
4. <http://wpi.edu/About/statements.html>
5. *See* - <http://www.wpi.edu/News/Journal/Spring97/plans.html> - *a WPI Plan historical summary.*
6. <http://www.wpi.edu/Pubs/Catalogs/Ugrad/Current/require.html>
7. <http://www.wpi.edu/News/Transformations/2006Fall/theplan.html>
8. <http://wpi.edu/Academics/Projects/>
9. Text excerpted from material provided by Dr. Richard Vaz, Dean of the WPI Interdisciplinary and Global Studies Division (IGSD). *Also:* <http://www.wpi.edu/Academics/Depts/IGSD/About>
10. <http://www.wpi.edu/Academics/Depts/IGSD/>
11. <http://www.wpi.edu/Pubs/Catalogs/Ugrad/Current/mqp.html>