Achieving Learning Outcomes Through Project-Based Education

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Abstract — *The WPI Plan is predicated on the concept that project work provides an environment in which students "learn by doing." In addition to requiring disciplinary competence, WPI's undergraduate programs feature broad learning outcomes such as the ability to address open-ended problems, to communicate effectively, to function well in teams, and to understand the societal and cultural contexts within which science and technology function. A set of required projects is central to the achievement and demonstration of such learning outcomes. As a practical matter, we have found that problems drawn from the "real world" provide very effective learning experiences for students working in small teams with guidance from faculty advisors and sponsor liaisons. WPI students complete two such projects --an interactive technology/society project done in multidisciplinary teams, and a capstone design or research project in the major area of study. Both of these projects are degree requirements for every WPI student. Assessment indicates that these experiences are especially effective contexts for motivating high levels of student achievement. Because of WPI's well-established project-based approach to global learning, the Global Perspective Program, more than 500 WPI students participated last year in semester-long study-abroad programs culminating in a major team-based project. The WPI Global Perspective Program presently provides opportunities at over twenty sites for students to complete disciplinary and interdisciplinary projects — all of which are advised by faculty in residence with the students at the global site. In this paper, we will discuss the educational objectives of these two types of student projects in terms of outcomes and their assessment. In particular, we will focus on the challenges and benefits of achieving and measuring broad learning outcomes in open-ended project settings. Some of these learning outcomes are particularly well-suited to demonstrating fulfillment of ABET criteria, including those criteria that are most difficult to achieve in a conventional, course-based curriculum. We will conclude by describing how the evidence provided by assessing these projects has been used in two highly successful ABET EC 2000 reviews.*

Index Terms — *assessment, accreditation, global, outcomes, projects*

Introduction

At WPI, students learn both through courses and projects, and the curriculum relies heavily on synthesizing previous learning during the conduct of project work. In fact, three of WPI's degree requirements are the satisfactory completion of specific types of projects. These requirements apply to all majors: science, engineering, computer science, humanities and arts, and management.

The WPI curriculum is outcomes-based and the faculty have defined the specific outcomes. While many of those outcomes will likely be achieved in project work, there is no *a priori* specification as to which outcomes might be achieved in any given project. There is, therefore, no straight-forward means of administratively conducting an inventory inasmuch as every student can, potentially, achieve the entire set of outcomes in different ways. Thus disciplinary and interdisciplinary departments, faculty governance, and the provost's office work together to monitor whether and how well each student satisfies each WPI learning outcome. But ultimately assessing the achievement of outcomes means more than assuring compliance with graduation rules—as important as that is. Rather, it is the program improvement that occurs through feedback of that assessment information that is of enduring value.

Background

We focus here on two of the required projects: the interactive project and the discipline-specific research or design project (known internally at WPI respectively as the Interactive Qualifying Project or IQP and the Major Qualifying Project or MQP). The interactive project requires work at the interface of technology and society while the major project requires the integration of prior studies through completing a technical project in the major field of study. These projects share a number of fundamental characteristics:

1. Nine credit hours of work achieved
2. Team approach – typically three students collaborating
3. Written and verbal communication required
4. Open-ended problem addressed, solved, and documented.

The interactive project provides an opportunity for students to study the interaction of technology and society. In simple terms, many of these projects involve the study of the effect of technological development on our society or, alternatively, using technology to solve societal problems.

More than half of these society-technology projects are completed through WPI's network of international project centers, often in the student's third year. (For specific information. see the WPI Global Perspective Program at www.wpi.edu/+global.) Local sponsors who are wrestling with local problems supply an unending list of potential project topics. For example, much of what the city of Venice needs to know to maintain its system of canals comes from a long series of WPI projects. Projects in Namibia, Costa Rica, and Puerto Rico have provided location-specific assistance and analysis around subsistence and commercial aquaculture. The residents of the Klong Toey slums of Bangkok have benefited from a diverse array of projects. A strategic carbon reduction initiative in London is built around the efforts of several project teams. Nearer campus, the Mayor of Worcester has publicly praised the contributions of WPI student teams to the city's economic development.

When these projects are completed on campus without explicit external sponsorship, they tend to study social implications of technology, frequently in an educational setting, or they grow out of faculty expertise in areas like medical economics or medical ethics. Students are often drawn into sophisticated encounters with issues of policy and practice. Summaries of completed society-technology projects from on- and off-campus may be reviewed at the WPI website under the WPI Global Perspective Program, Exploring Completed Projects, http://www.wpi.edu/Academics/Depts/IGSD/Interactions/.

The research or design project in the major field, typically carried out in the senior year, provides opportunities for students to apply and draw together all their prior learning in order to solve a technological problem in their major. This work may range from single student research programs (more commonly in the sciences and mathematics) to analysis, design, or planning projects with external corporate or government sponsorship. Some of these experiences are residential as well at locations including Silicon Valley, Lincoln Labs, Goddard Space Flight Center, Wall Street, Glenn Space Flight Center, Analog Devices in Limerick, Ireland, and the Institut National Polytechnic de Lorraine in Nancy, France.

This work is often similar to traditional senior design projects, but it is frequently informed by the realities of the sponsor's current needs and depth of experience. For example, student teams at the Goddard Space Flight Center simulate master-slave satellite systems that are under active development. Mechanical engineering students at the MIT Lincoln Laboratory analyze the vibration behavior for an antenna deployment system that will be launched. Several major manufacturing corporations can quantify the dollars saved by WPI project teams.

In both of these types of projects, both faculty advisor(s) and agency sponsors (typically referred to as the project mentor) are involved in substantive ways. Finally, students learn to work like professionals by making numerous progress reports (written and verbal), adhering strictly to a sensitive schedule, and making a well-rehearsed final project report and presentation. The outcomes achieved by such project work are embedded in these interactions, reports, and presentations.

An additional outcome is the broad range of off-campus, particularly international, experiences. Typically, about 40% of a graduating class will have completed at least one project outside the continental U.S., another 20% will have worked at a domestic project center; and about 10% of graduates have had two or more off-campus project experiences. Among bachelor's graduate in all majors, WPI ranks second nationally in the fraction of its graduates in all majors, not just science and engineering, who have studied abroad [1].

Learning Outcomes

WPI has codified its expectations of learning outcomes, Table 1. These outcomes were developed by a special faculty committee, the Undergraduate Outcomes Assessment Committee, and were adopted by faculty vote through the Committee on Academic Policy.

Graduates of WPI undergraduates will:

1. Have a base of knowledge in mathematics, science, and humanistic studies
2. Have mastered fundamental concepts and methods in their principal areas of study
3. Understand and employ current technological tools
4. Be effective in oral, written and visual communication
5. Function effectively both individually and on teams
6. Be able to identify, analyze, and solve problems creatively through sustained critical investigation
7. Be able to make connections between disciplines and to integrate information from multiple sources
8. Be aware of how their decisions affect and are affected by other individuals separated by time, space, and culture
9. Be aware of personal, societal, and professional ethical standards
10. Have the skills, diligence, and commitment to excellence needed to engage in lifelong learning.

TABLE 1
WPI UNDERGRADUATE LEARNING OUTCOMES

There is obvious similarity to the ABET, Criterion 3 Program Outcomes and Assessment list, Table 2.

1. An ability to apply knowledge of mathematics, science, and engineering
2. An ability to design and conduct experiments, as well as to analyze and interpret data
3. An ability to design a system, component, or process to meet desired needs
4. An ability to function on multi-disciplinary teams
5. An ability to identify, formulate, and solve engineering problems
6. An understanding of professional and ethical responsibility
7. An ability to communicate effectively
8. The broad education necessary to understand the impact of engineering solutions in a global and societal context
9. A recognition of the need for, and an ability to engage in life-long learning
10. A knowledge of contemporary issues
11. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

TABLE 2
PROGRAM OUTCOMES AND ASSESSMENT

Assessment of Achievement of Outcomes

In many instances, achieving an outcome is self-evident because the project could not be completed without demonstrating it. For example, a student could not complete a project satisfactorily without demonstrating effective written communication. Other outcomes either may or may not be achieved through project work. For example, “understand and employ current technological tools” might be found as a given project outcome, but if not, will have to be found elsewhere in the WPI requirements The first problem is, therefore, determining which outcomes are achieved in a given project. The second problem is determining to what extent the outcome has been achieved. A subcommittee of the WPI Committee on Academic Policy, the Undergraduate Outcomes Assessment Committee, is charged with identifying where in the WPI curriculum opportunities exist for students to achieve each outcome, to help guide faculty assessment activity.

Interactive Projects

Several years ago, WPI instituted a periodic review of all interactive project reports completed during a calendar year. A team of paid faculty reviewers is trained and calibrated for the assessment, using an in-house designed evaluation form. Reviewers rate the report quality for items like:

1. problem and objectives definition
2. literature reviews

3. choice of methodologies
4. results interpretation

as well as for achievement of WPI learning objectives like addressing the society-technology interactions; and for evidence of several ABET outcomes (4, 6-10 from Table 2 above).

Results consistently show that projects completed off-campus are significantly better in nearly all respects than those completed on-campus. For example, on a scale of 1=poor, 3=acceptable, and 5=excellent, overall report quality averages 4.20 for off-campus projects and 2.98 for on-campus projects. Reasons for the large difference are related more to student motivation, preparation, and project management and less to academic differences between the two cohorts. The faculty and administrators overseeing the interactive project program have combined these assessment results with other analyses to design improvement processes for on-campus projects. Initial results are encouraging.

This project review is a serious, detailed, and comprehensive exercise [2]. Without it, the significant differences between on and off-campus projects would have been obscured. As a result of this assessment information, WPI has identified specific reasons for the difference and made informed judgments about curriculum changes for program improvement.

In addition to this internal assessment, WPI has initiated studies probing more general student learning aspects. One project seeks to understand how the interactive project experience prepares students to learn on their own, and how the project experience changes their attitudes toward learning. The Self-Directed Learning Readiness Scale has been invaluable for this work [3]. The SDLRS measures students' readiness for life-long learning. Although the work is in progress, preliminary results show positive changes in SDLRS occur during the off-campus project experience [2] – [3].

The Project in the Major Field

Every two years each engineering department reviews all the major project reports completed during that time period. We'll use the Chemical Engineering Department as an example to describe that process. The ChE department contracts an external reviewer from local industry to read every report and rate it in several ways. (Other departments typically use their own faculty.) Demographic and statistical information are collected, but more importantly, report content and quality are rated. The department has 15 learning outcomes that map into the ABET a-k shown above. Of the 15, the project report is expected to show evidence for 11 outcomes. The reviewer rates the extent (evidence present, or not, for an outcome) and quality (from poor to excellent) of each of those outcomes. The reviewer also looks for integration and application of students' previous chemical engineering, mathematics, and science coursework--a major goal of the disciplinary project.

This project is a major experience where students display evidence of desired outcomes. Assessment results show that all 11 of the ChE department outcomes appropriate for the project and 8 of 11 of the ABET outcomes are met to a defined minimum level in all projects. This means that students must show evidence for other ABET outcomes through other academic experiences. These results indicate that a major project experience specific to one's discipline can provide an excellent opportunity to demonstrate learning.

Our review goes beyond this. For example, the ChE department found that single-student projects consistently rate lower than multi-student projects, and that externally sponsored projects (typically by local industry or sponsors at off-campus sites) consistently rate higher than on-campus projects. The department finds it unrealistic to have all projects externally sponsored but is working to minimize the number of single-student projects. Another problem identified is that although ChE and basic science coursework is integrated well into the project experience, there is an unacceptably low level of mathematical rigor. Each faculty advisor is urged to be diligent in getting students to increase their level of quantitative analysis, particularly statistical data analysis.

Outcomes and ABET Self Study

Assessing the achievement of outcomes through project work has been used not only to improve the curriculum, but also to demonstrate achievement of ABET expected outcomes in two highly successful reviews. In 1996 WPI was one of the first two universities to undergo self-study and ABET review using then EC2000. Between 1996 and 2002, when the next ABET general visit occurred, WPI scrutinized its assessment procedures in depth and created an effective on-going review jointly conceived and managed by faculty and administration. WPI makes available at www.wpi.edu/Academics/Outcomes extensive information and analysis on all its learning outcomes assessment activities. Available here are the full self-studies for all engineering programs, which lay out in detail the methodologies used to assess learning in projects and courses, the analyses undertaken of the resulting data, and the departmental and committee discussions leading to changing the curriculum to improve opportunities for learning as needs are defined by these reviews.

Each department updates its assessment portfolio on this website at least every other year, since WPI is committed to on-going assessment and critical review. Under "Assessing Academic Programs" on the Web site, several engineering departments provide detailed reviews conducted since 2002 of the student learning outcomes disclosed by review of the major design project. Each departmental review identifies problems recognized in the past, as well as solutions proposed and assessed to address those problems. For example, Biomedical Engineering provides a detailed study of student learning from assessing their major projects in these areas: experimentation, analysis and interpretation of data, design, identifying and solving problems, use of contemporary tools, overall capstone design, team work, communications, social impact, contemporary issues, and professional and ethical responsibilities. Specific recommendations to alter the curriculum to improve learning include identifying specifically how external sponsors of projects provided support to the outcomes, and providing a brief history of the evolution of design work.

Conclusions

Finding and assessing the learning achievements in projects is not straight-forward, but, given the appropriate assessment designs and resources, it is quite possible and very effective. At WPI it has been found that the regular review of the success of a project-based program in meeting higher-level learning objectives stimulates faculty as much as the project experience stimulates students.

REFERENCES

[1] Davis, T. M., Open Doors 2001/2002: Report on International Educational Exchange, Institute of International Education, New York, N.Y. retrieved March 1, 2004, from the World Wide Web: http://www.opendoorsweb.org/, 2003.

[2] DiBiasio, D. and N. Mello, "Assessing a Nontraditional Study Abroad Program in the Engineering Discipline", in press, Frontiers: The Interdisciplinary Journal of Study Abroad, 2004.

[3] Litzinger, T., S. H. Lee, and J. Wise, "Assessing Readiness for Self-Directed Learning", Proceedings of the ASEE meeting Nashville, TN, June 2003.