Enhancement to Student Learning by Employing Advanced Computing in a Project Oriented Environment

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Abstract
A partnership between an individual donor, industry and academia has been formed to develop a crucible where the hypothesis that advanced computing can enhance student learning in a project oriented environment will be tested. We have developed a facility that provides a location, previously lacking, for teams of students to participate in capstone experiences. The purpose of the facility is to provide a site and vehicle that enables partnerships between industry, faculty, and students. This partnership is designed to produce a synergistic experience for students from all majors in the context of interdisciplinary, open ended projects. The hypothesis is that the co-location of student groups, and the existence of a shared advanced computing infrastructure, will lead to improved learning outcomes for student participants. This paper describes the generation of a crucible where students can undertake defining educational capstone experiences that fully reflect new ABET criteria. This paper treats the effort used to define the computing resources and systems required to support this goal, as well as the implementation of assessment criteria to measure the achievement of objectives in support of this goal. In addition, it contrasts student experiences before and after the implementation of advanced computing resources. It highlights the value of these resources in support of ABET student learning objectives, and in the embellishment of student experiences. The new facility is a place where industry and academia have come together, where education and the "real world" have come together, and where computing and engineering have come together to create an environment where students grow into enabled engineers for the 21st Century.

I. Introduction

Hands-on, learn by doing education is an expensive proposition. Fortunately, the returns on investments in this form of educational practice have justified the expense. True education resides in experiential learning, however, not all experiences are equally valuable. We must optimize our students experience. Laboratory intensive education and a capstone senior project requirement have provided Poly graduates with a margin for excellence. This exposure is valuable because engineers are inherently innovators, the nature of engineering is problem identification and solution. Engineers have designed and built the structure and the infrastructure of society in each and every era, and in each and every sector. From chips to ships, from "It" to "Freedom" engineers use the materials of their age to shape their world. Thus, if the laboratories and the senior project are to continue to provide value, they cannot remain static, they must reflect the current environment, and current practice in the industrial sector. Today's engineering world is full of potential and is almost surreal in scale and scope. It provides a tempting prospect for nascent engineers to develop new engineering wonders.

However, support for these activities must come from industrial sponsors and from philanthropic individuals and organizations. Recent events have clearly demonstrated that state support cannot provide the resource necessary for laboratory based education or for capstone student experiences. In our era of fast-paced scientific discovery, spectacular engineering achievement, and complex social systems, it is clear that everything is connected to everything else. We have learned what we attempt to teach our students, the best way to move ahead is in partnership and collaboration. Academe, industry, individuals and government all have played a critical role in maintaining educational quality, but the world is changing rapidly, and we need to keep pace with those changes. This partnership is the *sine-qua-non* in engineering education, it has passed from a luxury to an imperative.

The Bonderson Engineering Projects Center is an extraordinary facility that enables students and faculty to undertake the kinds of hands-on projects that have long distinguished the College of Engineering. It is an exemplar of the partnership between a dedicated individual and a dedicated faculty and college. The donors stated goal summarizes the intent of ABET 2000. He says, “My goal in supporting this facility is to foster the same kind of creative engineering experience that was so helpful to me. I want students today to have the opportunity to undertake truly cutting edge projects, especially multidisciplinary projects, because that’s what industry needs today.” The Center provides large, flexible workspaces, equipped with the latest technology. It ensures the continuation of our acclaimed “learn by doing” pedagogy; it symbolizes the very future of undergraduate engineering education. To prepare students for the 21st century, we must expand our time-proven, hands-on, project-centered teaching model. Most importantly, we must provide physical locations that allow students an opportunity to undertake “real world” projects – interdisciplinary and multidisciplinary projects that provide a seamless connection between the discipline dominated academic sphere and the function dominated professional world. Students must have access to the tools of modern research; access to state of the art technology and equipment and access to the growing database of engineering and computer science scholarship. Finally, students must be given the opportunity to work collaboratively across disciplines and around the globe. These activities will enable our students not only to engineer, but to engineer well.

The Bonderson Center will provide a location for slightly disorganized or chaotic activities that characterize regions of intellectual advancement. A place where related things do not quite lock into place, but potential linkages do not quite evaporate either. In short, a place where students can eat away at the boundaries of what is extant. This facility is a space to juxtapose unlike partners and diverse ideas, to feed the imagination and to encourage risk.

Historical Perspective
The educational process for engineers in the United States post 1950 was dramatically affected by the experiences of World War II. The technical demands of the war for new developments made clear the shortcomings of engineering education at that time. The Hammond Reports (1940, 1944) and Grinter Report (1955) stressed that "engineers required a deeper understanding of fundamentals that could be applied broadly, and less emphasis on current technical practice". These reports, when coupled with a growing awareness of the rapid growth of knowledge, the ever accelerating pace of technological advances and the complex and intertwined social, economic and technical relationships evolving in society, led to drastic alterations in engineering curricula. Engineering education attempted to integrate physical science, mathematics, engineering science, social science, economics, humanities and analysis in an unprecedented attempt to accomplish both breadth and specialization in a four-year degree. Because of this effort, several key exposures were eliminated. At many institutions, the unintended victims of this effort were integration and synthesis, engineering design, engineering process, laboratories and device centered approaches to education.

This flaw in engineering education manifested itself in economic trial. Throughout the 1970's and early 1980's, U.S. industry, in almost every sector, was being battered by international competition. Foreign companies capitalized with more innovative design, more agile manufacturing, greater productivity, higher quality and lower prices. Part of the problem was an engineering education system that graduated students with an inadequate understanding of the engineering process. They lacked an ability to convert engineering knowledge into real gains for society. In the ensuing twenty years, what has evolved is a partnership between government, industry and academia to the benefit of each and to the benefit of society.

The new era presents many opportunities for the engineer. The rapid pace of technological innovation impacts engineers directly, bringing new power and new responsibility. Post cold war international politics brings different conflicts and new partnerships. The blurring of the distinctions between defense and commercial industries creates vast new possibilities. Markedly improved global communication and low-cost computing power diminish the importance of national boundaries.

Clearly, as reflected in ABET 2000 Criteria, nascent engineers must be exposed to systems integration and synthesis as well as engineering science and analysis. They must practice problem forming as well as solving. They must be able to design and to realize products. To be successful, engineers will need to have facility with intelligent technology to enhance creative opportunity. They will also need the ability to manage complexity and uncertainty, to function as productive members of teams, and to be sensitive in and to interpersonal relationships. The emphasis in engineering education programs must shift from a dedication to course content to a more comprehensive view. It must focus on the development of human resources and the broader educational experience in which the individual curricular parts are connected and integrated. We must place emphasis on the development of students as emerging professionals with the knowledge base and capability for life-long-learning. We must engage students in engineering from the day they matriculate and make the study of engineering more attractive, exciting and fulfilling. Engineering students must be given the opportunity to experience the defining activity of engineering, to design - create something that has never been. They must learn to design to meet the full range of objectives encountered in actual practice. They must understand manufacturing and construction and have the ability to realize products. They must be able to create and operate complex systems. They must understand physical constructs and the economic, social, political and international context in which engineering is practiced. Finally, they must be committed to "life-long-learning". The Bonderson Center, and the partnerships it provides, creates a vehicle to accomplish many of these objectives.

In the Bonderson Center, the borders between discovery, learning, and innovation are becoming ever more blurred. Engineers are working across many different disciplines and fields and in different sectors to make the connections that lead to deeper insights and more creative solutions. The engineers of the future will use this capacity to integrate knowledge in new ways. The capacity to discover, to learn, and to innovate that we develop in the Center activities is the key skill that will enable our engineers, and our economy, to weather the storms of change, and the quite natural evolution of engineering and economic systems.

II. Computing Advances

Recently, advances in computing technology have created the opportunity to bring massive computing resources to bear on engineering problems. Algorithms have been developed to bring computing into engineering synthesis, not simply data acquisition and analysis. Computing systems hold the promise of renewing education itself, not simply by changing delivery modes, but by allowing us to more clearly understand and couple to human learning mechanisms. In the 1990's, computing brought us the information age – and computing revolutionized the communications industry. In the next decade computing and engineering will combine to create a knowledge age – where computing will be fully integrated into engineering infrastructure. The Bonderson Engineering Projects Center has placed the future of engineering education in view and within reach.

The nation's computing capability has served as a catalyst to all of science and engineering. Similarly, in the Bonderson Center our goal was to build the most advanced computer-communications infrastructure possible for researchers and educators to use, and to broaden its accessibility. We are focused on providing computational power, a broader band network, copious storage and memory capability and state-of-the-art system interfaces. Our goal is to create a robust computer-infrastructure in the facility.

Interestingly, many new educational technologies have features consistent with basic principles of learning. The interactive feature helps students learn by doing, receiving feedback, and refining their understanding. Technologies help people visualize concepts that are difficult to grasp. And technologies provide access to a universe of information that includes digital libraries, real-world data, and people for both information and feedback.

The Bonderson Engineering Projects Center is an independent facility designed to provide for students a hands-on “learn by doing” environment. The purpose of the Center is to provide a vehicle that enables partnerships between industry, faculty, and students. This partnership is designed to produce research for industry and provide real-life projects for students in the form of thesis and senior projects, which are required for graduation. Thus, the implications of the Bonderson Center are a win-win environment for all involved. Industry, faculty and students work in partnership to create a greater educational experience. Industry gets inexpensive educated talent that is equipped to hit-the-ground-running on their current projects and issues. Students and faculty get current and future state-of-the-art projects that give an immediacy and relevance to augment their traditional studies.

Progress in education in the 21st century depends upon access to world-class tools. Clearly, available infrastructures can either expand or inhibit our potential facility potential. We must be ever vigilant, an infrastructure system can provide potential in one era, but drag us into obsolescence in another era. It must be thought of as a perishable entity. This is an important understanding because what was *avant-garde* yesterday is state-of-the-art today, *derigueur* tomorrow and *passé* at the end of the week.

III. Vehicle Requirements

The college has developed a strategic plan to invest in people, the tools they need to accomplish their goals and in the ideas they generate. As previously mentioned, the Center will be a location that tolerates, or even fosters purposeful disorder. It will provide students space to make messes, make mistakes and the discoveries critical to their educational exploration.

The Bonderson Center is the vehicle to produce the next level engineering graduate. It provides a unique environment that is specific to engineering discovery. There are no faculty offices or traditional classrooms in the facility. The Center is made up of various laboratories that create an educational research model that enable the student and faculty to focus on the projects specified by their industry sponsors. Our goal was to create a “boundaryless” laboratory, free of most hierarchical constraints. Engineers, educators, and entrepreneurs are working across many different disciplines and fields and in different sectors to make the connections that lead to deeper insights and more creative solutions. Our professionals of the future will need this capacity to create, integrate, and use knowledge in new ways.

- Space – The Bonderson Center consists of more than 20,000 square feet of state-of-the-art applied research space divided into 20 reconfigurable interdisciplinary laboratories. These laboratories enable the students and faculty to plumb real-life-engineering projects.
- Technology – A number of companies have generously donated computing technology to be used in the facility. These computing resources consist of large servers, high-end work-stations, a tape library for data archiving, and a number of smaller workstations scattered

throughout the building.

- Communication infrastructure – The computers are networked together using switched 10/100BaseT Ethernet hubs and category 5 cable. This infrastructure is connected to the campus backbone via a 100 MB fiber FDDI connection.

IV. Use of Communications / Computing Technology in the Bonderson Center

The network design was developed to insure fast computer networking capability. A minimum specification of switched 100BaseT hubs and category 5 cabling was designed to each network faceplate in the facility. Each room has at least three pairs of network access ports installed. Most of the building network infrastructure was designed using external cable conduits thus allowing for easily accessible communication upgrades -- as technology evolves with a modicum installation expense and educational downtime. With the fast networking available, students and faculty have access to applications and data stored on the multiple servers within the facility. The necessity of fast networking infrastructure allows users instantaneous access to data and applications from servers as if it was accessing this information on the local computer. The design of the architecture is meant to provide a flexible user environment, provide for leveraging and sharing resources and to minimize administration or maintenance needed on desktop.

V. Student Access

The Bonderson Center is a resource that is open to all students. It particularly enables those working in groups or teams, on interdisciplinary projects founded in a synergy of perspectives. It is a place for collaborative independent study. It serves students through several venues.

Simulations Laboratory. The open simulations laboratory provides students with platforms for many of the existing laboratory simulation programs (see below). This facility serves many of the same functions and is often used in conjunction with the virtual laboratory. The main distinction is the web-based nature of the virtual laboratory.

Virtual Laboratory. In the open virtual laboratory students can use courseware available on the web as directed by faculty, or as driven by their own curiosity. The explosive growth of the net, and the birth of I2, has led to the incorporation of web-based experiences into many courses. Students can use the facility to work offline on homework or other course assignments. They can use it to develop project-based work, as an e-enabled study hall and interaction center. The use of computers in education is not new, what is new is the power of the individual computer and the capabilities for networking. This laboratory uses the computing capability as a powerful element in the educational arsenal, it does not use the computer as a surrogate television but provides for asynchronous experiences. The computer provides content and interaction; it does not simply transfer information.

We are also working to develop a “remote operation” capability. The lab-centered approach to education is recognized as a cornerstone of effective engineering education by a number of stakeholders. These include the academic community, accrediting agencies and national foundations. Cal Poly has a century-long tradition of laboratory-based instruction, and we are reviewing what the true manifestation of this form of instruction will be in the 21st Century. In the context of our partnership in I2, several faculty have interacted with colleagues at other universities and at national laboratories in efforts to effectively utilize expensive or one-of-a-kind hardware. Currently we are developing candidate laboratories in Mechanical, Aeronautical and Manufacturing Engineering on campus to develop stronger capability in this area, with an eye to extending the sharing capability for more mundane apparatus. Our hope is to make our lab centered experience available to more students at more times.

Video-Teleconferencing Center. The video-teleconferencing center is used by groups of students working on thesis or senior project efforts. It is typically used in formal design review sessions, but is also used to solve immediate, pressing challenges students have in real time. Usually, these are hardware specific problems best discussed while examining the component.

Written Communications Laboratory. Many studies have indicated that communication skills, as manifested in speech or the written word, are essential to the career progression of engineering professionals. The senior project is a integral part of the Cal Poly educational experience, but one that can delay graduation of our students. Often this delay is associated more with writing the document that performing the work associated with the project. This laboratory provides as asynchronous interactive writing center. It gives students help with senior project and thesis composition. It also makes use of interactive materials for the development of technical writing skills.

Engineering Ethics Center. Engineering ethics is a critical component of the background of all engineering professionals. This is now formally recognized by academic accrediting agencies, it has been well known by corporations. Ethics is a field similar to engineering, where there are often few clear correct or incorrect answers. Decision-making is an optimization process, where one chooses the best out of the universe of available responses. The engineering ethics center is a self-paced facility for individual instruction where students move from simple pedantic exercises through more involved to deep case studies and finally to interactive video experiences. The ethics center is particularly exciting because it can be used as an assessment tool for ABET, to quantify the capabilities of students exposed to ethics in the curriculum. This is potentially quantifiable information, which can detect improvement in performance over time. It provides the rare testable hypothesis.

VII. Conclusion

The Bonderson Center is a unique collaboration and provides benefits to all participants. The Center provides a crucible where students can undertake defining educational capstone experiences that fully reflect new ABET criteria and the new millennium. It is a place where education and research have come together, and where students grow into enabled engineers for the 21st Century. The center is a place where, to paraphrase Mark Twain "education will not interfere with learning." The experiences shared by students at the Center will occur in an increasing diversity of contexts that integrate learning with research and the work environment, as well as in a variety of modes, excellent exposure for life long learners. The Bonderson Center will provide the capacity for risk taking and for imagination, it will provide a vehicle for students to develop tolerance for uncertainty. In these troubled times, it's worth remembering that engineering and technology are often our best bulwark against chaos. The Bonderson Center will help nascent professionals develop the capability to provide for progress as defined by Alfred North Whitehead, who said, "The art of progress is to preserve order amid change and to preserve change amid order."

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