AC 2009-1499: DEVELOPING SUCCESSFUL INDUSTRIAL INTERACTIONS IN SUPPORT OF PROJECT-BASED LEARNING: AN ORGANIC MODEL

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Developing Successful Industrial Interactions in Support of Project Based Learning, an Organic Model

Abstract

As engineering education at the undergraduate level continues to evolve, the support structure required for educational approaches such as Project-Based Learning (PBL) is expanding to include not only the Department, College, and University levels, but also significant commitments from industrial partners. While the benefits of project based learning approaches are clear, there are a number of challenges in establishing and maintaining the deep level of institutional and industrial interaction required to create a successful program. Three elements have been found to be keys to success of project based learning in the university environment. First the persistent and intimate involvement of agencies external to the university in the projects. This is critical from the standpoint of project development, realization and assessment. Second, the participation of faculty steeped in project management experience, who have the demonstrated ability to produce a "product" within a timeline. This is vital to helping student teams over the subtle hurdles to product realization. And finally, the flexibility to find ways to step outside the artificial timelines associated with university educational practice. This is essential to beginning a dialog with industry, or other external partners. Based on the results at the Project Based Learning Institute (PBLI), our external partners find project based learning valuable enough to underwrite a major portion of its direct costs as well as to support it with the participation of their employees. The partnership satisfies three critical objectives. First, it enhances the curricular objectives of the college and satisfies the learning outcomes required of our students. Second, it provides a mechanism to underwrite educational costs by delivering value to industrial partners, a vital college constituent group. Third, it provides a vehicle to bridge the void between our professors and their colleagues in industry, providing common ground for communication and a vehicle to professional development.

Introduction

The development of a robust industrial interaction underpins many successful academic programs on a variety of levels.[1,2,3] PBLI has provided a new relevance to students and faculty in tying their work directly to external agencies. Work becomes more meaningful and fulfilling as its significance is defined in its relation to, and impact on, other things. PBLI participants do not have the common academic flaw of possessing an answer in search of a question. Instead, through strong relationships between industry and academia they develop the pertinent questions and seek relevant answers.

To maintain or enhance its position in the 21st century, the U.S. will rely on a continuous supply of well-educated, professionally-oriented engineers to augment those educated in the traditional research-based programs focused on the Ph.D. pipeline. Engineering education in the United States replicated the template employed in educational programs housed in colleges of science. These templates were developed in reaction to a report prepared in 1945 in reaction to experiences during World War II.[4] Engineering programs grew mimicking these structures and developed policies typical of the colleges of science. This one-size-fits-all approach neglects

fundamental philosophical differences between science and engineering. Admittedly, the distinction between science and engineering is often blurred, and the very best of engineers and scientists are tantamount to indistinguishable. However, science is typically driven by discovery, and its main output is information, whereas engineering is driven by creation and its main output is innovation.

The nation's requirements for innovation clearly show that educational programs must provide engineers who can deal with both design and manufacturing. It is important and justifiable to include much science and engineering science in an engineering curriculum, but that alone is not adequate preparation for a career as an engineer. Furthermore, colleges of engineering cannot just be a stop on the educational assembly line which takes decreasing numbers of high-school students with widely varied levels of preparation, provides them with an academic exposure to theory and then graduates them to be trained, as needed, by their employer. Students must be educated to be life-long-learners, and industry and the university must become constant and persistent collaborators in this process. This will require universities to rethink the educational paradigms which have shaped engineering education for the last half century.[5] PBL is one approach that provides a solution to improving the education of incipient engineers on campus and engineers on the industrial site. Instead of a "step function" interface between the college and industry, this model provides a "sigmoidal segue" between the two.

The College of Engineering has recently established the Project Based Learning Institute (PBLI) to address this need by enhancing its current "learn-by-doing" approach to education. This new institute is the catalyst for bringing together the needs of the industry, the students and the faculty. In this paper, we will provide one approach adopted by PBLI in developing project centered relationships with external organizations. This is not a seed change in the college's approach to education, rather it is a natural evolution and enhancement of the process. It is the 21st Century manifestation of a fundamentally sound educational approach. The college has a long history of using a learn-by-doing approach to engineering education. Indeed, it is embodied in the motto of the university "*Discere Faciendo*", to learn by doing. Through this pedagogical approach, understanding theory is facilitated and enhanced by demonstrating its application to the real world situations. This learning and teaching paradigm has allowed the colleges graduates to be more productive *ab initio* in their professional careers than their counterparts with a less rigorous laboratory and project based exposure. As evidenced by the growth of the "learn-by-doing" approach to education in the United States and the rest of the world, project based learning has been accepted as a valuable component in the educational experience of nascent engineers.[4,6,7]

The College of Engineering Strategic Plan states that: ***"The mission of the College of Engineering is to be a flagship college of engineering that benefits humanity by educating socially responsible engineers inspired for life-long learning using an innovative learn by doing philosophy in partnership with industry and other stakeholders."*** The PBLI is consistent with the College mission because it promotes the use of a multi-disciplinary, participatory, learn by doing, "hands-on" laboratory, project and design centered approach. The PBLI enhances educational outcomes for students in accordance with the strategic plan, it enhances the professional development of the faculty in conformance with the strategic plan, by encouraging and supporting expansion of faculty research and by provide appropriate infrastructure for

faculty, including adequate computing/information systems and technical support, and it enables relationships with industry in harmony with the strategic plan.

Universities have employed a plethora of approaches to create industrial partnership in the educational process. PBLI serves as an academic incubator that has been used to overcome institutional inertia by creating a structure that lies outside existing well-established educatioal "territories". PBLI is self supporting by nature, which allows resource issues which typically shackle academic initiatives to be obviated. The program has developed into a catalyst for industry participation that benefits both students and corporate sponsors. While the benefits of the relationship between academia and industry are clear, a wide range of challenges in the implementation of PBLI were encountered and overcome. After two years, PBLI has established deep seated relationships that transcend individual contacts. This allows PBLI to develop a perseverance more robust than that of any individual involved in the process. The juxtaposition of high-potential faculty, coupled with incentives for multi-disciplinary faculty collaboration, embellished by more effective access vehicles for industry to university resources, and a more effective mechanism to uncover and respond to industry needs, has produced an educational outcome that provides for an engineering graduate who is steeped in multidisciplinarity, who is exceptionally team-oriented and who is able to function in today's complex environment.

Preparing the engineering workforce for both public and private sectors is a significant task in the face of the intensifying global competition. Engineers of tomorrow must be able to work in an increasingly interconnected world with a diverse group of colleagues from dispersed geographical locations. The ability to solve real problems facing businesses hinges on a multi-disciplinary education enriched by general skills in teamwork, communication and project management. The PBLI is underpinned by the principle that durable, robust, sustainable partnerships between faculty, students and industry are beneficial to each stakeholder.

The Basis for PBLI

Because of the growth of the college, the unfunded, single-project, single-student, single-advisor model is not sustainable, neither is it academically desirable in most cases. Several courageous faculty have come together, under the rubric of the PBLI, to explore pan-departmental (and pan-college) associations of students and faculty working on externally supported activities that satisfy not only the design requirements in the curriculum, but may address other outcomes mandated by accreditation, by department goals or by university initiatives.

There are a number of sources and sinks for projects at the institution. These include the capstone design courses that are an integral part of each departmental curriculum, the senior project and thesis requirements for students, and the individual interests and efforts of both students and faculty. In the current nascent stage of the PBLI there are a range of activities across the spectrum of departments. Unit requirements for the capstone design experience range from 4 to 9 quarter units, senior projects are occasionally integrated with capstone design, but many are stand-alone classes or individual study experiences. Single student experiences are the norm, with a few departments offering "interdisciplinary" experiences. Projects range from instructor selected activities across an entire course to self-selected and created projects. Many

projects are not funded externally, some programs have developed an infrastructure to seek external funding and these instances are invariably multi-student and interdisciplinary.[8]

The initial effort does not mandate a project format, but focuses on the voluntary participation of a number of motivated faculty to develop a course centered around high-quality, multi-disciplinary capstone projects that can be accomplished in a pertinent academic timeframe using PBLI as a self-sustaining infrastructure. Clearly, costs associated with project based learning are an impediment to its implementation.[9] *Ab initio* we have sought the participation of industry, or other external agencies driven not only by pedagogy, but also by resource imperatives. Furthermore, we implemented PBLI as a capstone experience. Some investigators have shown that using project based learning as the main pedagogical device at early stages in the student's university career may be less effective than lecture exposures.[10] In engineering, some key topics are best characterized as very hierarchical knowledge structures underpinned by complex analytical skills. Though these can be used in project based learning, it may not be the best vehicle for students to learn them. Throughout the curriculum, the pedagogical value of project based learning must be balanced with its motivational significance.[11]

Clearly, exposure to problems, and the use of technology to solve design challenges in response to those problems are critical components in the education of engineers. The progression of the nascent engineer from a knowledgeable user of technology through naïve problem solver to an artisan and finally an expert is expedited by project based learning exposures.[12] Whereas the analytical underpinnings of the complex design process may best be taught in lecture formats, with abstract representations and in less open-ended laboratory experiences, the complex design process itself requires higher-order thought and is best accomplished by exposure to concrete applications in a project based learning environment.[13]

Androgogy, not Pedagogy

Much of learning theory, even as applied at the university, has classical pedagogy as its basis. The word pedagogy comes from ancient Greece and means "to lead the child". The term andragogy is more appropriate when discussing adult learning and the teaching of young adults at the university. Knowels has pointed out that adults need to be involved in the planning and evaluation of their instruction, that for adults experience provides the basis for learning activities, that adults are most interested in learning subjects that have immediate relevance to their job or personal life, and that adult learning is problem-centered rather than content-oriented. [14]

PBLI bridges this gap for adult learners. Students are engaged and learn about things important to them and have developed clear expectations among themselves and for themselves. They choose from real problems, and identify potential solutions, and challenges. They develop project management skills, defining tasks among groups that are self selected, and identify key challenges. They are full participants in a needs driven, self directed, open-ended environment. After students research the projects available, they select their project of interest based on a points bidding system. The groups brainstorm, and develop requirements and materials needs. They plan and schedule, and develop assessment tools and learn the importance of delivering results. PBLI educational experiences are learner centered, authentic in content and purpose, challenging at an appropriate level, stress product development, presentation skills, performance,

collaboration, cooperative learning, and continual improvement. They are facilitated, not by lectures, but by just in time intervention by faculty and industry participants.

Learning Models

The primacy of the individual-student, independent-study model was driven by historical factors that governed the development of the institution, and by the availability of infrastructure. A number of factors now provide the opportunity to create a more academically beneficial, a more interactive and a more vigorous system. The College is committed to the departmental structure, and understands the value that structure provides in the educational environment. Similarly, the college understands the value of loose federations of departments, joined in response to both operational requirements and strategic opportunities. In our system, this federated structure provides benefits in scheduling laboratories, optimal usage of laboratories, optimal assignment of office spaces, optimization of instructional delivery patterns for faculty and for lecturers. It also provides benefits by increasing the opportunities for interaction among individuals, promoting the creation of interdisciplinary curricular approaches that satisfy educational objectives and student outcomes in a better and a more efficient way and potentially offers a more sustainable approach to admissions. The structure recognizes partnerships and common interests that exist in instructional laboratories, and also recognizes interdisciplinary laboratories and soft-money facilities. Use of the PBLI spaces and the interdisciplinay spaces is limited to those activities involving students and faculty from a number of programs, joined in efforts on a particular project.

Thus, PBLI is viewed as a non-departmental entity that has the potential to provide the funds and infrastructure to support pan-program efforts, including Senior/Capstone projects. PBLI serves to create an intersection of incoming targeted funding, customer-based project opportunities, students seeking multidisciplinary capstone experiences and faculty who are interested in this alternative to department-based efforts. PBLI serves as the focus for activities and provides the interface upon which “planktonic” entities can become “sessile” around concentrated resources and produce stable activity centers based on their competencies. The self-supporting infrastructure is critical, as any existing multidisciplinary efforts have a hidden cost to the hosting department, and this cost would become significant and limiting as multidisciplinary activities increase. The obvious source for this resource is industry and foundations.

Defining Projects

The PBLI staff normally take the lead in working with the engineering team from the participating industrial organization in order to agree on the broad scope of the projects. With this knowledge, the staff can identify the most suitable faculty to lead these projects. In the next step, the selected faculty will meet with the engineering team from the partner organization (in person or using a conference/web meeting) in order to refine the problem description. This step is very critical since, on one hand, we want the problems to be challenging and rewarding for the students and, on the other hand, we want to avoid assigning projects that are beyond the reasonable stretch of students capabilities.

During this stage the reporting arrangement will be discussed and the liaison from the partner organization will be identified. The availability of a technical liaison among the partner's engineering team is a critical success factor. The interaction between the liaison and the students allows the partner to select the most suitable student for future employment. At the same time, the students will be able to learn much from the technical liaison not the least of which is corporate culture. The liaison's role is to make sure that the student's questions are answered so that the project remains within the original boundaries.

One approach to creating linkages follows. During the first week of the quarter, an engineer from the partner organization will make a presentation to a large group of students – often is a particular class- about the organization and the project. This allows students to sign up for the available projects. The faculty will take this information into account when assembling the teams and assigning the team projects.

The student teams are then assembled and the project starts on the second week. The projects are normally two quarters long (10 weeks per quarter). During the first quarter the teams are engaged in the design of the solution. At the end of this quarter there is a single design that the students feel can address the problem posed. In the second quarter the students build a physical prototype, test it and document it. The final stage of the project is a presentation to the partners and a written report.

Another approach provides a database of projects and allows interested students to bid for participation, in much the same way some career centers allow students to bid for interview slots with particular companies. In either of these cases students select their projects and are, *a priori*, more motivated.

Clearly, one lesson learned is that PBLI should embrace a full spectrum of project levels, a full spectrum of student levels, and a full spectrum of timeframe levels. Participants in PBLI should not be consumed by policy rather than practice and define themselves out of relationships with potential participants. Don't say no – find the appropriate student for the appropriate project at the PBLI interface.

Industry Memberships

We have established two levels of membership for prospective partners. In the Standard Memberships, for a fixed annual fee, the partner will propose several projects out of which 3 projects will be selected. The selection is based on the fit between the project scope and content and the learning objectives as set by the faculty members involved in the senior design project. There are four levels of annual memberships, Founder, Premier, Champion and Affiliate, with annual fees of $100K, $50K, $25K and $15K respectively. In the Premium Memberships, which are one-time donations that create a lifetime relationship, the partner can propose an unlimited number of projects. These projects will be presented to students and any project with a sufficient number of interested students will be carried out. The premium memberships also provide the sponsor a seat on the Advisory Board for Project Based Learning. There are two levels of Premier membership, Lifetime at $250K and Patron at $500K.

In addition to the annual and lifetime memberships, we offer single project participation to small companies in our Associates program. Our goals here are to expose many organizations to the benefits of working with Cal Poly, and to grow the relationship into an annual membership.

PBLI currently has three Lifetime Members, two Founding Members, five Premier Members, ten Champions and three Associate Members. The PBLI staff includes a Managing Director, three Resident Scientists/Engineers, two dedicated faculty and an Administrative Assistant. In addition other faculty participate on an *ad hoc* basis by project. There are currently over sixty on-going projects, each project involves two to six students.

Benefits to the University Community

Student education through a project based learning paradigm is the top priority at the College of Engineering. It is therefore, obvious that we benefit immensely from the direct involvement of our partners. In addition, by being in a regular contact with the engineers from the partner organizations, our faculty will learn about the learning objectives that they should incorporate into the curriculum in order to align our students' skill set with the needs of the industry. Graduating students are our primary products at the college and the partners are the primary customers for this products. It is, therefore, critical that the customer participate in all stages of the product development. Our graduates are known to hit the ground running on day one with little on the job training required. Our goal at PBLI is to help train engineers who can be productive on the first day of their employment. In addition, through working in a team environment, our graduate can play as an effective team member and utilize all of the non-technical and leadership skills they have learned through their senior design experience. (In addition, our graduates are in high demand upon graduation, which is a quality that will attract even more competitive applicants to the university in the future)

Benefits to Industry Partners

Cal Poly's College of Engineering is known for its hands-on approach to engineering education. Our approach to engineering education uses a project-based teaching/learning strategy that has enabled our program to attain national recognition as the exemplary model for undergraduate engineering education. Combining this practical approach with a strong theoretical foundation is producing engineers that are sought after throughout California and its neighboring states. As such the demand for our top graduates is very high. Instead of relying on general purpose job fairs, the PBLI members have an opportunity to "test-drive" a number of students over an extended period of time. This familiarity is an excellent platform for selecting the candidates with the highest demonstrated capability.

In addition, the relationship built during the project execution between the faculty advisor an the technical liaison can expand beyond the senior design project. As a result of this extended interaction, the faculty members learn about the critical issues that our partners would like to address and the partners in turn learn about the capabilities of our faculty and the applied research infrastructure at the college.

Academic Platforms for PBLI

The general engineering program in the College of Engineering is a unique multidisciplinary program designed to produce competent engineers across all engineering disciplines. The mission of the General Engineering program is to provide students with the highest quality technical and professional engineering education, with a particular emphasis in new or evolving interdisciplinary areas. The primary educational goal is to provide students with a rigorous theoretical, laboratory-centered, practice-oriented, hands-on education that will allow them to immediately participate and to excel in the complete spectrum of professional environments, industrial or academic. Graduates will have engineering, design and problem-solving skills requisite to develop and market competitive products and services for human benefit. With its emphasize on a multi-disciplinary education, this program is a natural ally to the Project Based Learning Institute.

Persistent Challenges

The senior design class is designed and executed at the departmental level and as such it is natural that they have grown in different directions. Each departmental faculty has designed a course they deem to match the learning objectives of that department. While this model works for a given department, it does not lend itself to a multidisciplinary project environment. Success of our program hinges on the ability to engage a large number of our senior and junior students in a multi-disciplinary project environment without being limited by the interdepartmental boundaries. Developing a uniform structure for all senior design projects is, therefore, of utmost importance to our efforts. An alternative approach may be to offer a multidisciplinary senior design class offered through the general engineering department that can be substituted for the departmental level senior design class based on students' desire and interest.

In addition, the challenge of attracting and retaining volunteer senior engineers must be properly managed as the number of incoming projects increase. A streamlined process for stewardship and for delivering the sough after value to the clients is also a critical success factor for PBLI.

From Practice to Theory

PBL will never and should never supplant all traditional instruction in engineering schools like it has at some med schools. It might not be the best way to learn basic skills, but it must be a critical component of the undergraduate engineer's educational experience. In going from practice to theory – instead of theory to practice it is an opportunity to turn normal progression on its head. It becomes an occasion for students to revisit and better learn the material they have been exposed to previously

PBLI can be seen as a model of Darwinian process at work in the educational environment. PBLI is most aptly described as a spontaneous "mutation" in the academic environment, something academics would call "innovation" in educational processes. PBLI still has the "genes" of the university, an organizational memory that allows it to navigate the university environment. Like any organism, PBLI is made up of individuals (cells or organs) with a common overall purpose, but many different core competencies (functions). The educational system is certainly stressed

now, in that competition for resources may favor mutations such as PBLI. This new species may flourish in an environment where traditional support mechanisms for education vanish, and long standing educational approaches may become "extinct".

Conclusions

The PBLI partnership satisfies three critical objectives. First, it enhances the curricular objectives of the college and satisfies the learning outcomes required of our students. Second, it provides a mechanism to underwrite educational costs by delivering value to industrial partners, a vital college constituent group. Third, it provides a vehicle to fill the void between our professors and their colleagues in industry, providing common ground for communication and a vehicle to professional development and relevance

We have presented an outline of the mission and activities of a new initiative, the Project Based Learning Institute. Several models for acquisition and managing industry sponsored projects have been described in detail. With eight (8) industry and government members in its first year of operation, the PBLI seems to be able to serve as a successful model for university industry relationship. It has been robust, and flexible enough to accommodate the different needs of each member. Perhaps the biggest challenge facing this new institution is to facilitate a transition from a departmental level senior design course to a multi-disciplinary and intra-departmental model. The bottom up approach, where courageous faculty are enabled to create functional implementations has been shown to work. It is a slower process than declaring that all projects will be structured in that fashion, but it is enduring and embraced by faculty. This evolutionary approach to curricular change is not as gaudy as some revolutionary efforts which have been made, but it has the potential of being more persistent. Three elements have been found to be keys to success of project based learning in the university environment. First the persistent and intimate involvement of agencies external to the university in the projects. This is critical from the standpoint of project development, realization and assessment. Second, the participation of faculty steeped in project management experience, who have the demonstrated ability to produce a "product" within a timeline. This is vital to helping student teams over the subtle hurdles to product realization. And finally, the flexibility to find ways to step outside the artificial timelines associated with university educational practice. This is essential to beginning a dialog with industry, or other external partners. Based on the results at the PBLI, our external partners find project based learning valuable enough to underwrite a major portion of its direct costs as well as to support it with the participation of their employees.

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