AC 2012-4901: INCREASING STUDENT LEARNING VIA AN INNOVATIVE CAPSTONE PROGRAM

Dr. Scott Danielson, Arizona State University, Polytechnic

Scott Danielson is the Associate Dean for Academic Programs in the College of Technology and Innovation at Arizona State University. Before assuming that role, he had been the Interim Chair of Engineering Department and the Chair of the Engineering Technology Department. He has been active in ASEE in the Mechanics Division and the Engineering Technology Division. He has also been active in ASME, being awarded the 2009 Ben C. Sparks Medal for excellence in mechanical engineering technology education, serving as a member of the Vision 2030 Task Force, serving as Chair of the Committee on Engineering Technology Accreditation, serving on the Board of Directors of the ASME Center for Education, and serving as a member of the Mechanical Engineering Technology Department Head Committee. He has been a Program Evaluator for both the Society of Manufacturing Engineers (SME) and ASME and currently serves on the Technology Accreditation Council (TAC) of ABET, representing ASME. He also serves on the SME's Manufacturing Education and Research Community steering committee. Before joining ASU, he had been at North Dakota State University, where he was a faculty member in the Industrial and Manufacturing Engineering Department. His research interests include machining, effective teaching, and engineering mechanics. Before coming to academia, he was a Design Engineer, Maintenance Supervisor, and Plant Engineer. He is a registered Professional Engineer.

Dr. Chell A. Roberts, Arizona State University, Polytechnic

Chell Roberts is the Executive Dean and former Chair of Engineering for the College of Technology and Innovation at Arizona State University. As Executive Dean, he serves as the College's Chief Operating Officer. As the Founding Chair of Engineering, Roberts led a clean slate design and development of a new engineering program created to be responsive to the latest knowledge on engineering education. He is currently leading the development of highly innovative programs at the intersection of traditional disciplines for a new college model that brings together engineering, science and business in a multidisciplinary fashion focusing on innovation and entrepreneurship. The newly developed curricular model is studio based and highly flexible. As part of the program development, Roberts has created a corporate partners program that has resulted in a high level of industry leadership and funding of multidisciplinary senior projects. Roberts received a Ph.D. in industrial engineering from Virginia Tech, a master's degree in industrial engineering from the University of Utah, and a bachelor's degree in mathematics from the University of Utah. Roberts has published more than 70 technical articles, has guided more than $2 million of research, provided consulting services to many companies, and served on many national conference organization committees, national review boards, and technical committees. Roberts's primary research and teaching interests are in the area of engineering education, computer simulation, and manufacturing automation.

Improving Student Learning via an Innovative Capstone Program

Introduction

Due to ABET accreditation requirements[1], all engineering and engineering technology programs include some sort of capstone design experience for their students, often done implemented within a single engineering discipline. But, it has been recognized that such disciplinary capstone experiences have higher value than accreditation and may not be sufficient. For example, *Educating the Engineer of 2020*[2] suggests an earlier and stronger introduction to engineering practice within undergraduate programs, with the students experiencing an iterative process of design, analysis, building, and testing. Crawley et al.[3] argue for educating engineering students via the 'Conceive-Design-Implement-Operate' paradigm so that they will be able to produce value-added engineering products in a modern team-based environment. Sheppard et al.[4] assessed current engineering education practices and then argued in support of an educational model where components of engineering science, laboratory work, and design activities interact with one another in an approximation of professional practice. Happily, there are examples of engineering education programs that have created or modified their program objectives and curricula to meet such curricular calls[5, 6, 7]. More recently, the ASME Vision 2030 Task Force has joined others in endorsing the utilization of a design spine across the curriculum. Ideally, this design spine is multidisciplinary in nature, providing the students with multiple experiences working with people from other disciplines as they progress through their curriculum culminating in a yearlong senior capstone design-build experience with a focus on system design, building, testing, and operation.[8]

The Challenge

In a uniquely pervasive manner, Arizona State University's College of Technology and Innovation (CTI) values learning of engineering in context (often called engaged learning or "hands-on" learning). As a result, CTI engineering education programs have infused authentic practice-based experience in the student's educational experience. Examples of such experiences include realistic projects and problems mirroring the situations CTI students will encounter in their professional engineering careers. Characteristics of these experiences include students working on interdisciplinary teams, where interdisciplinary implies a broad spectrum of skills (e.g., management, technology, different engineering disciplines, computing, psychology, or the natural sciences) depending on the project. As one example, the CTI's engineering program and multiple engineering technology programs have successfully implemented two semester interdisciplinary capstone projects involving industry sponsors.

A number of challenges inhibit creation of an environment where authentic practice-based experiences can be a significant element of **all** students' engineering education experience. These included the following challenges.

1. There was a need for large numbers of team-based projects to enable all the students to have such experiences.
2. A traditional engineering degree program is not structured for pervasive interdisciplinary practice-based work. In particular, programs often lack flexibility within their curricular

layouts. Simple operational details such as a common class meeting time can inhibit multiple programs/departments from breaking down disciplinary educational silos. Every degree program has a set of prerequisites for capstone and faculty that teach these courses often operate independently. Some programs may use a one semester model for capstone and others, a two semester capstone experience. Thus, capstone projects are typically discipline specific.

3. Scale rapidly becomes an issue–space conducive to student teams and project work is needed—and space for expanded numbers of student due to multidisciplinary projects may be beyond the reach of an individual program.
4. Mentorship of the student teams is needed–most faculty are not trained by their graduate research experiences to be good mentors of student project teams.
5. A different financial model is needed–increasing the number of authentic practice-based multidisciplinary team projects costs money and separate departments can inhibit funding models that reach across units. That can be an added difficulty in a time of decreased funding for most institutions.

The Innovation Idea

Arizona State University's College of Technology and Innovation developed a college-wide engineering education program centered on iProjects (where the "i" can stand for many things, including industry, innovation, or impact). CTI engineering program leaders have been formulating the iProjects innovation idea for the past five years and began implementation three and a half years ago. As expected in a dynamic environment, implementation is never finished. As success became apparent, the project scope expanded with the goal of involving more students in more projects in a wider interdisciplinary environment. We are not finished with implementation, nor do we expect to ever be "finished." However, we have accomplished the original design goals. The iProjects program includes the following features.

1. Strong external engagement. An ideal source of authentic practice-based project experiences is industry, government and the community. With these partners, students involved in such projects engage in solving real engineering problems for, and with, external partners. This enables the external partner to solve a business/engineering problem and provides the students an excellent learning experience, a classic "win-win." The partners provide the problem, they pay for a solution and, most importantly, provide joint mentorship of the student team. Of course, initially, it was difficult to engage a large number of external constituencies. This has been a development process since money and projects, at a scale where many students would be involved, is both needed and not a simple task to obtain.

The CTI has engaged a broad spectrum of external sponsors via these iProjects. Industrial partners range from large aerospace and defense contractors, e.g., Honeywell, General Dynamics, Raytheon, technology oriented companies, e.g., GoDaddy and Advanced Micro Devices (AMD), aftermarket automotive companies, e.g., Flex-a-lite, and small startup companies, e.g., Vyykn and World Music Stage. Partnership is not constrained to the business sector, local governments like the citys of Gilbert and Tempe along with Sandia National Laboratory are current partners.

While inherently attractive from an educational standpoint, the solicitation and obtainment of funding to solve current problems of external partners has to stay within ethical and legal bounds.

Institutions of higher learning, if publically supported, are often constrained by state law with regard to competition with local industry. Thus, it is important to openly acknowledge that these are student projects and failure to produce a viable or commercial solution is possible. While a viable design and professional prototype is always the project goal, the educational experience, e.g., learning, of the students is still the most important aspect of the process. Thus, routine engineering solutions or production of large quantities of product are not appropriate due to lower educational value and increased chances of infringing on local industry. The developmental nature of projects and the resulting educational experience of the students are critical aspect of project selection.

2. Modifications to academic program's structure. Two structural needs were immediately identified. First, sufficient flexibility in the engineering education academic programs was needed so they would allow incorporation of substantive team-based projects, many of which would be interdisciplinary. Second, there was a need to have project courses that could be integrated college wide, e.g., course meetings at the same time.

3. Repurposing of space. Flexible project space was needed for teams to meet, to build prototypes as necessary, to host meetings with external partners, and to present the student's work. We have reconfigured space within the college to meet this need.

4. A viable financial model. A solid financial model was critical to the success of this initiative and had to be created. As inspiration, we found other programs that had obtained significant support for disciplinary projects and adapted their financial model.

This approach to improving and enabling pervasive CTI student experiences in an authentic practice-based educational experience was, and is, innovative. CTI faculty and administrators have found no one else is doing it in the country. Other engineering programs use external projects, but not in such a pervasive and interdisciplinary fashion. Certainly, many programs provide space for their student teams to work. But, the college-wide allocation of space, dedicated to free-flowing student use of the space for their team projects is very rare. Thus, CTI's providing an authentic practice-based, interdisciplinary team project experience for all engineering and engineering technology students was both groundbreaking and innovative.

Idea Implementation

Early in the implementation process, benchmarking of models used by other colleges and universities was accomplished. Such institutions included Harvey Mudd College, Rose Hulman Institute of Technology, Olin College, Cal Poly – Pomona and San Luis Obispo, Worcester Polytechnic Institute and Aalborg University in Denmark. These institutions are all widely know for their approaches to engineering education. For instance, Harvey Mudd and Olin have implemented non-traditional engineering programs, with a strong flavor of projects and/or multidisciplinarity in their programs. Rose Hulman consistently ranks at the top of the US News & World rankings of engineering programs without a doctorate. Aalborg University is renowned for their project-based approach to engineering education. Pomona and San Luis Obispo have strong reputations for applied engineering programs with facilities and faculty supporting students in engineering projects. During these visits and follow-up conversations, we developed models for implementation.

To accomplish the necessary changes in academic program structure, a common time as developed for all students in CTI so they could easily meet for interdisciplinary projects. At this point in the implementation, all the engineering education programs and several of the other college programs have transitioned. The CTI's B.S. in Engineering curriculum[6] had been designed to be project intensive, incorporating a project spine with project classes each semester, providing its students many opportunities to work on teams and to manage projects.

Strong external engagement was pursued. CTI hired the previous development officer for Harvey Mudd College on a short term contract to assist with corporate introductions, taking advantage of his connections at the Vice President, and higher level, within many companies. During the first year of implementation, meetings were held with 20 potential external partners. Often, a first meeting occurred at the potential partner's location with a second meeting at the Polytechnic Campus. With some partners, the process from introductions to securing support took up to eight meetings. After this first year, five of the partners agreed to provide a realistic engineering project for the students, to provide a project mentor for two semesters (we also provide faculty mentor(s)), and monetary support for the projects, with sufficient overhead that we could sustain the program. Importantly for the success of the industry involvement, we developed a model where the external partner could retain the intellectual property, if any, generated from the project. We also structured a set of feedback and engagement meetings to keep the partners engaged and to use partner feedback to improve the program. In 2011 – 2012, there are more than 20 sponsored projects that directly fund over 200 students in authentic, practice-based project experiences. We have also used residual funds to fund program support staff and non-industry sponsored student teams.

How capstone projects are initiated with the engineering students illustrates several key features of the program. After agreeing to sponsor a project, or more than one, the sponsor creates a proposal for each project, including a brief problem statement and budget. On the first several days of the capstone courses, all students from all engineering programs listen to short, five minute presentations on each project. Ideally, these presentations are made by the industry sponsor/mentor. After these presentations, students are given a short skill-set survey, which often reflects the projects being presented, asking questions about their skill sets. The students turn in this skill survey and a project list where they rank the top five projects they would like to work on for the year. The department chairs and capstone coordinators then review the surveys and student project interests to staff the project teams. A large majority of students are placed on one of their top three project choices. The students are not told who the faculty mentor will be or what the project budget will be, both mechanisms are intended to keep the students focused on the company project and not specific faculty they may want to work with on a project. The company mentors are then present at the next class meeting when the students are told which team they will be working on and the project starts immediately.

Repurposing space has been accomplished by the creation of a number of studios and laboratories for project realization, as well as space for teams to work together. We have developed prototyping centers where students go get help developing products. We also created a large open team space called "Start-up Labs" where student teams have space to generate and develop ideas and work on projects. This space is highly flexible and reconfigurable.

A financial model was created where we can scale the program based on enrollment. Within this model, sufficient funds are generated to not only maintain the projects, but to grow the infrastructure (e.g., equipment, space and people) supporting the programs. Sponsors agree to fund not only fund the project costs but also contribute to the cost of administering the program. While there is the occasional deviation from the standard funding model, most projects are funded at the same level. But not all projects cost the same amount to successfully meet the project's goals. Such residual funds are kept within the iProject program and serve to support various initiatives or staffing needs within the program. In addition, student program fees, separate from the iProject program, are available from the programs participating in the program. These monies can be combined to fund "departmentally funded projects" where the sponsor becomes a faculty member or administrator in the CTI. For instance, a multidisciplinary group of students designed and built a new wind tunnel for one of the programs in the college using this funding mechanism.

Partners

As noted earlier, we have many external partners in the development and implementation of this model. Some partners sponsor projects every year (a list that is rapidly growing) and some sponsor multiple projects (currently a maximum of five projects with their funding at the six figure level). These external partners include city governments, a national laboratory, and many companies, ranging from small start-up companies to large defense companies. Partners indicate that they engage in the program for several reasons. The primary reason is that running projects provides companies an opportunity to evaluate future engineering talent. The sponsors have hired many students from their project's team. The second motivation is to get something of value accomplished through the projects. Several sponsors use the projects to test new ideas, to generate out of the box thinking, and to explore new markets.

We hold a large public showcase event, the Innovation Showcase, in May to exhibit the projects and as a form of community and industry engagement. We expect to exhibit around 80 projects this year (some will come from class projects or traditional research projects not counted as capstone projects). We also engage the sponsors by having them provide assessment of the student work and projects beyond the project that their company sponsored.

Goals and Objectives of iProjects

1. Increased engagement. The goal of engaging all CTI undergraduate students in authentic, practice and team-based projects or learning experiences is being accomplished. All CTI seniors in engineering-related programs are involved in such projects, with additional involvement of other students from non-engineering majors.

2. Improve Student Learning Outcomes. We have developed a learning outcome: the ability to work on an interdisciplinary team. Prior to the program, very few students worked on an interdisciplinary team. Now a large number of projects have students working on interdisciplinary teams. Faculty assessment of this outcome indicates that the majority of students working on these projects have an increased ability to work on such teams.

3. Engage External Partners. We now have approximately 20 external partners that have participated in the program. The majority of external sponsors have also hired students as a result of their engagement with CTI. Several of the partners have created additional investments in CTI beyond sponsoring project teams, evidence that engagement often leads to increased engagement!

4. Redesign of CTI academic programs to be more conducive to iProjects and interdisciplinarity. Over half of all CTI programs have been designed or redesigned using a flexible, interdisciplinary model. The remainder programs are in the process of redesign. This will allow further enrichment of the teams by involving more non-engineering students in either engineering projects or other types of projects..

5. Restructure space. We have over 30,000 square feet of space for student teams to work on projects. This space has been purposefully designed. We also have a plan for another 20,000 square feet of space that will not require significant internal investment.

6. Acquire and train faculty mentors. Over 50% of the college engineering-related faculty have now mentored iProject teams. We have also involved a number of external project mentors and have plans to double that number in the next three years.

7. Develop a Financial Model. We have developed a sustainable financial model that allows the iProject model to grow and scale across the entire college. The program will eventually serve all seniors and many of the underclass men and women in the college, all units, all programs!

Program Success Measurement

Most success measurements for this program are quantitative and consist of counts of students, faculty and companies. These include the number of, or percent of, students involved in projects, number of, or percent of, academic program structured to enable involvement, square feet of space configured to support project experiences, number of faculty involved and the number of students hired by sponsoring project partners. Student outcomes are assessed on developmental scales using rubrics. In some cases, students are pre and post-evaluated on team-based skills. As the project continues to evolve, additional metrics will be established to look more deeply into the factors of student success, including additional outcomes. The iProjects program results over the past three years have been extremely positive. We expect that these trends will continue to be positive as this model is now a core model of the college.

The Future

It is the expectation, driven by the Dean of the College of Technology and Innovation, that all CTI students will have the opportunity to work on authentic, practice-based interdisciplinary projects. Thus, the set of external sponsors who engage at a high level in the college must be expanded. To meet the demands of such scaling, it will be necessary to enlist more mentors to help assess and mentor students, perhaps retired engineers or other professionals that wish to contribute to enhancing the education of students. It is hoped that the CTI programs will continue to be more embedded within the community and be seen as a way for them to engage ASU towards solving their community's problems. The transformation of CTI will continue towards becoming widely known as an innovative model of education. First phase results have informed the goals for the second phase of this work: a new model for faculty activity, a centralized assessment function that focuses on student outcomes, a new model for general studies, a restructuring of all of the academic programs, the development of new external partners, including other colleges and universities, and the development of promotion and tenure activities/evaluation aligned with these design aspirations.

Bibliography

1. ABET, Inc. *Criteria for Accrediting Engineering Programs, 2012 – 2013*. Accessed March 8, 2012. http://www.abet.org/engineering-criteria-2012-2013/

2. National Academy of Engineering (2005). *Educating the Engineer of 2020*. The National Academies Press, Washington D.C.

3. Crawley, E., Malmqvist, J., Östlund, S., Brodeur, D. (2007). *Rethinking Engineering Education: The CDIO Approach*, Springer, New York, NY.

4. Sheppard, S., K. Macatangay, A. Colby, &Sullivan, W. (2009). *Educating Engineers*, Jossey-Bass, San Francisco, CA.

5. Olin College of Engineering, http://www.olin.edu/academics accessed on February 29, 2012.

6. Morrell, D., Roberts, C., Grondin, R., Kuo, C.Y, Hinks, R., Danielson, S., & Henderson, M. (2005). A Flexible Curriculum for a Multi-disciplinary Undergraduate Engineering Degree. In the 2005 *Frontiers in Education Conference Proceedings*, IEEE, October 19-22, Indianapolis, IN.

7. Danielson, S., Hawks, V., & Hartin, J. (2006). Engineering Technology Education in an Era of Globalization, In the *2006 ASEE/IEE Frontiers in Education Conference Proceedings*, IEEE, October.

8. Kirkpatrick, A., Danielson, S., & Perry, T. (2012). ASME Vision 2030 -- Recommendations for Mechanical Engineering Education. In the *2012 Annual Conference Proceedings*, American Society for Engineering Education, June 10 - 13, San Antonio, TX. New York: American Society for Engineering Education.