2017 HAWAII UNIVERSITY INTERNATIONAL CONFERENCES
SCIENCE, TECHNOLOGY & ENGINEERING, ARTS, MATHEMATICS & EDUCATION JUNE 8 - 10, 2017
HAWAII PRINCE HOTEL WAIKIKI, HONOLULU, HAWAII

STRENGTHENING INDUSTRY/UNIVERSITY PARTNERSHIPS THROUGH MULTIDISCIPLINARY STEM/STEAM CAPSTONE PROJECTS

GARDNER, PATRICK
CENTER FOR RAPID PRODUCT REALIZATION
COLLEGE OF ENGINEERING AND TECHNOLOGY
WESTERN CAROLINA UNIVERSITY
NORTH CAROLINA

Dr. Patrick Gardner
Center for Rapid Product Realization
College of Engineering and Technology
Western Carolina University
North Carolina.

Strengthening Industry/University Partnerships Through Multidisciplinary STEM/STEAM Capstone Projects

Synopsis:

STEAM Capstone projects with industry. The presentation includes (1) How companies are recruited and how cross-disciplinary teams are formed; (2) Process for organizing/executing projects; (3) Processes for tracking progress, reporting results, and applying lessons learned; (4) Methods for ensuring course credit and accreditation requirements are satisfied; (5) Vehicle for compensating faculty (across campus) in team mentor roles; and (6) How intellectual property is managed.

Strengthening Industry/University partnerships Through Multidisciplinary STEM/STEAM Capstone Projects

Patrick Gardner, Ph.D.
Center for Rapid Product Realization
College of Engineering and Technology
Western Carolina University
Cullowhee, NC 28779

Abstract
Project-based learning is a theme for all engineering programs at Western Carolina University (WCU). The Center for Rapid Prototyping (Rapid Center), housed in the College of Engineering, provides services to external clients spanning design, analysis, 3-D scanning and 3-D printing and business counseling for applications spanning automotive, aerospace, medical, and arts. Faculty and students from all of the STEAM disciplines across the campus participate in solving client problems. The Director for the Rapid Center, a professor in engineering, teaches the 2-semester engineering capstone course. Over the last four years, we have formed project teams that have included engineering, business and health sciences (nursing, physical therapy) students to collectively solve client problems or develop new products. For the 2017-18 academic year, we are extending team to include arts and sciences students. We have created a process whereby the administrative burden for projects is minimal, with all agreements, contracting and invoicing managed from the Rapid Center. The Rapid Center and the Technology Transfer Office jointly manage all Intellectual Property (IP) concerns. In this paper we provide a summary of the capstone construct – how companies are recruited and how cross-disciplinary teams are formed; methods for ensuring course credit and accreditation requirements are satisfied; the process for organizing and executing these projects; processes for tracking progress, reporting results, and applying lessons learned; a vehicle for compensating faculty (across the campus) in team mentorship roles; and a means by which IP ownership is managed.

Keywords: Capstone projects, multidisciplinary student teams, Project-Based Learning

1. Introduction

Project-Based Learning (PBL) is a core theme in all of the engineering degree programs at WCU. Successfully instituted and integrated in many universities over the last two decades, we share many of the common PBL instruction strategies [1]. Simply cataloged with "ENGR" prefixes, all engineering majors participate in at least one PBL course in each of their four years of education. We introduce students to courses through which instruction is enveloped by realistic and globally relevant problems requiring innovative solutions by "multidisciplinary" teams; that is, teams comprised of students from two or more of the engineering majors [2]. In the first year, we challenge student teams to design, construct and demonstrate noncomplex electromechanical systems. By Year 3, student teams are proposing projects to solve real world problems, encompassing renewable energy, automation, recreation, etc. The PBL sequence culminates in Year 4 with a two-semester engineering capstone course. Here, we form (true) multidisciplinary teams to solve relevant problems for companies, inventors and government agencies. Historically, and still prevalent today, engineering faculty view "multidisciplinary" as a teaming of electrical and mechanical engineers, for example, to solve a systems level problem. What we find in practice, however, is that our engineering graduates are quickly teamed with members from project management, supply chain and logistics, contracts, graphic design, technical writing, marketing and branding, etc. Recognizing this reality, we have moved in the direction of building true multidisciplinary capstone projects teams, recruiting students from all STEAM fields, as required, to solve some of the most open-ended and compelling problems for industry. In this paper, we describe a partnership model that emerged from the engineering and business colleges at WCU; however, any college or department can develop a similar model, anchored by a central office that manages the contracting and administrative burdens for the departments.

2. Multidisciplinary Capstone Projects

A successful STEM/STEAM multidisciplinary capstone project program requires a committed team of leaders and mentors from sponsoring companies, inventors or agencies; academic colleges and departments; and (ideally) a central contracts and administration office within the university.

2.1 Recruiting Capstone Sponsors. WCU is a small rural university without an abundance of large donors or alumni leading large corporations. As such, we actively seek industry sponsors throughout the year for the upcoming academic year. We exercise active external engagement through several centers within the university – The Rapid Center, The Small Business and Technology Development Center (SBTDC), and the Corporation for Entrepreneurship and Innovation (CEI).

The Rapid Center, housed in the College of Engineering, provides services to external clients spanning design, analysis, test, 3-D scanning and 3-D printing, and business counseling for applications spanning automotive, aerospace, medical, and art (https://www.wcu.edu/learn/departments-schools-colleges/cet/rapid-center/index.aspx). As a standalone cost center, the Rapid Center may contract directly with external partners to provide fee-for-service assistance. Clients range from individual inventors to large corporations, and project complexity ranges from 1-day turnaround to multi-phase, multi-year endeavors. As we assist clients, we look for those projects that have the right complexity, scope, and multidisciplinary content along with those clients that are willing and able to sponsor a student team for two semesters. The director for the Rapid Center is the instructor of record for engineering capstone, and so the transition from client to capstone sponsor is seamless.

The North Carolina SBTDC is a business advisory resource for growing and developing businesses, providing services statewide from offices hosted by campuses of the University of North Carolina System (http://www.sbtdc.org/). The SBTDC is often the first entry point for small and startup businesses in North Carolina, and clients are regularly referred to the Rapid Center for technical design and development assistance.

Housed in the College of Business, the CEI, also with its own cost center, promotes entrepreneurship and economic development across the university and throughout the region (https://www.wcucei.com/). Prior to its establishment, the College of Business was unable to provide direct fee-for-service assistance to entrepreneurs and businesses looking for assistance, leaving many needs in the community unmet. Additionally, clients had few to no options available for seeking early stage investment in an idea or product. The CEI works closely with regional partners including the Pinnacle Enterprise Angel Fund to bridge gaps in early stage funding for promising start-ups. The director of the CEI is an instructor of record for the College of Business capstone projects, and so the transition from client to capstone sponsor is seamless.

In close partnership, the Rapid Center and the CEI, augmented by SBTDC business counselors, identifies capstone sponsors for multidisciplinary projects. The Rapid Center currently manages contracts and invoicing; however, either center may take lead. In fact, any organization on campus may lead multidisciplinary capstone projects. The major challenge is to balance customer expectations and the varying credit and accreditation requirements across academic departments. We address this topic in the next section.

2.2 Building Multidisciplinary Teams. A highly functional multidisciplinary team cannot be force fit. For example, a team should not have an electrical engineer if there is no electrical content. Intuitive, but faculty often drive to "check" the multidisciplinary box when it is not how a company would build a project team. The key is to identify projects up front that have multidisciplinary content. As an example of a successful multidisciplinary project, WCU is completing a capstone project for a local physician. She came to us with high-level concepts for a novel cervical collar. The team we assembled was comprised of students from Physical Therapy, Nursing, Business and Marketing, and Mechanical Engineering – approximately 15 students. Next month the team will deliver a functional prototype, which will have been through initial clinical testing, along with a market analysis and draft business plan. The team will also deliver a provisional patent, with a few of the team members listed as co-inventors. The innovative components of the collar were 3-D printed in the Rapid Center. The CEI is poised to take the prototype to a commercial product with angel fund investment. The Sponsor has been involved in weekly discussions since the beginning.

In another project, we designed and constructed a gazebo-like structure on campus where students could "dual-recharge" - charge their electronic devices using solar energy, while relaxing in hammocks. The team named the project "Electronic Garden on the Green" (EGG, http://news-prod.wcu.edu/2016/10/wcus-electron-garden-green-becoming-popular-hangout-students/). The team was comprised of electrical and mechanical engineering students, as well as interior and graphics design majors. A cross-campus team of students evaluated the progress and determined levels of investment to complete the EGG. Campus Facilities Management served as the customer and levied all customer-level expectations on the team – technical, schedule and budget management.

The major obstacle we have encountered in these multidisciplinary projects is balancing project demands and the realities of academic course credit and accreditation requirements. The engineering capstone course spans one academic year, while other departments have one-semester capstones. We have managed this in two ways: (1) Building a master schedule whereby a team, say from the arts, participates only in the early conceptual phase, or (2) Handing the project off to a new team in the second semester. Both methods are effective, both mimic a corporate model for team management, provided there is a faculty mentor and a sponsor representative that covers the full year. Course credit need not be for capstone. Team members, say that do not have capstone, may participate for credit towards independent study, an honors contract, fulfillment of a scholarship, etc. WCU recently instituted the *DegreePlus* program under its Quality Enhancement Program (QEP). Under *DegreePlus*, students may receive service credit for participation in these sponsored projects.

Individual departments can best manage satisfaction of accreditation requirements. In engineering, we have developed a cross reference of the so-called "a through k" criteria for the Accreditation Board for Engineering and Technology (ABET) and standard expectations of an industry sponsor for project development (Table 1). As part of our PBL sequence for ABET reviewers, engineering students are expected to participate in multidisciplinary, in this case multiple engineering disciplines, for their capstone project, and this accounts for approximately 90%+ of our projects. Our objective is to compliment these with 3-5 projects each year that also draw from other STEAM disciplines across campus.

Table 1. Satisfying accreditation requirements and customer expectations simultaneously

What Accreditation Reviewers Expect	What Industry Sponsors Receive
• Understand and articulate a problem • Identify an approach for a solution using known models and processes • Demonstrate the application of constraints on a problem • Demonstrate the application of constraints on a solution • Demonstrate logical problem solution methods, starting with multiple solution approaches • Compose effective written technical communication • Deliver effective oral communication • Demonstrate timeliness in meetings and contributions to a team	• Formal Kick-off meeting • Literature reviews; specialized applications training • Requirements analysis; Budget review • Compliance guides (e.g., OSHA); budget review; schedule review • Conceptual to detailed design data; Trades; Drawings • Formal reports; design documentation; formal reviews • Formal reviews (4) • Weekly Activity Reports; Complete project binder; Deliverables

3. Organizing and Executing Projects

3.1 Organization. Project organization is a yearlong process. Projects may come in from company requests, faculty contacts or students. At WCU, students may nominate a project for capstone, but there must be an external advocate who is willing to participate in mentoring, and ideally, provide financial sponsorship. We have established a process whereby students from any of the STEAM disciplines may "pitch" an idea to a panel of investors at the CEI. If selected, the project moves to the College of Business or the College of Engineering as a capstone. Before execution, the project must be fully coordinated with all stakeholders – sponsors and faculty

from each relevant department. Mentors are identified, and in true multidisciplinary projects, there should be multiple faculty from various departments engaged. This is all completed before a student team is formed. At WCU, industry sponsors pay a small unrestricted sponsorship, and some of that is placed in professional development accounts for the faculty mentors (see Section 3.4). Student teams may be formed in a variety of ways. Typically, an engineering team will meet their business, arts and sciences, etc. teammates for the first time at the beginning of the semester. In cases where a small group of students pitches an idea to the CEI, they become the majority of the project team, provided it aligns with individual department criteria.

3.2 Project Execution. In an attempt to mirror best practices in industry, project execution follows the Project Management Institute (PMI) standards for project planning, execution and control [3]. The following is a typical task list for engineering students (all projects):

- Problem Statement & Customer requirements
- Objectives & Scope of the project
- Work Breakdown Structure & Master Schedule
- Risk Assessment & Risk Management
- Material & Budget Plans
- Progress/Activity Reports (weekly or biweekly)
- Designs & Prototypes
- Test & Verification of Requirements
- Final Report with designs, drawings, test results

Much of this list is common for other disciplines. Student teams document all projects throughout the year on Blackboard™ (http://www.blackboard.com/learning-management-system/blackboard-learn.aspx). Thought of as an academic tool, Blackboard has a sufficient level of security measures to be deemed ITAR compliant [4, 5]. All students entered into the class (across campus) may access common course material, but we can limit access to individual team folders. We provide access to external sponsors as "Community Members," where they have read/write access to a specific project folder. For sponsors with more restrictive firewalls, we manage project documentation through their own SharePoint, VPN, etc. To be successful, we ask sponsors to be fully engaged with the project team throughout the year though weekly calls or visits, weekly activity reports, and periodic formal reviews (four per year). The projects end with a large public symposium, where students present their results. Figure 1 is an example of a symposium project poster.

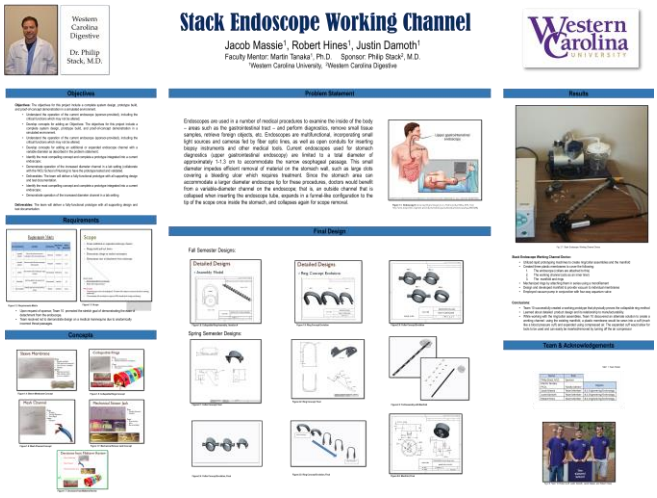

Figure 1. Poster example. This team collaborated with the School of Nursing for product evaluation.

3.3 Continuous Process improvement. Every project and every student team is unique – each has examples of successes and failures, and we only improve the program through regular feedback and application of Lessons

Learned. Over the academic year, students have two opportunities to provide formal course feedback. We encourage actionable comments on things that work and things that do not work in the course. We have students complete a CATME™ (http://info.catme.org/) survey twice per year – a self and team assessment. Finally, we have students write a reflection paper at the end of the year. We apply themes from these instruments yearly, and one of the recent themes from our students was a request to have more multidisciplinary STEAM projects to better reflect real world experiences.

3.4 Compensating Faculty for Mentorship Roles. Every capstone project team has a dedicated faculty mentor for the entire academic year. The mentor meets weekly with the team, participates in reviews, and provides general guidance to the team and the industry sponsor. While it may be helpful, the mentor does not need to have subject-matter expertise for the project. In fact, for multi-disciplinary STEM/STEAM teams, it is not feasible. Rather, the mentor and the student team should know where to seek specific expertise within the university. For example, the cervical collar project team has a mentor with an electrical engineering background. That mentor also has experience in product development, and with the team, they seek input from mechanical engineering, business, physical therapy and nursing to successfully design, prototype, fabricate and test the device. The provisional patent application is written by the student team with assistance from a campus patent agent. In some cases, it is helpful to have more than one mentor, for example, from both engineering and history. In those cases, there is always one principal lead to avoid leadership confusion for the student team. The co-mentor does not typically direct the team.

All of our project mentors are volunteers – not the type of volunteers that come from a pool of tenure track faculty – rather, these volunteers cut across rank and seniority and may include fixed term and adjunct members. The entire college, and as we move to more STEAM projects, the entire university embraces success for this initiative. Faculty have the opportunity to review a catalog of projects and select one (or two) that align with their interests with regard to topic area or industry sponsor. All faculty that lead project teams may apply their mentorship as "Service" for tenure review, post-tenure review, or annual performance evaluations. However, at a small university, there are endless opportunities for Service credit, so we also compensate faculty mentors through a vehicle we call "Faculty Spending Accounts" or FSA. The FSA is applied as a percentage of the sponsorship payment, and for WCU, the sponsorship is typically $2,500 and faculty receive $1,000 in their FSA. Faculty may use it for professional development (such as renewals for professional societies), equipment and supplies, pay for student workers, or they may draw summer salary. The FSA rolls over from year to year, and for small universities like WCU, faculty may accumulate a significant balance. It is also not unusual for a faculty mentor to collaborate with industry sponsors outside of capstone.

3.5 Management of Intellectual Property (IP). A very common question associated with university assistance to industry, including capstone projects, is "How is IP ownership managed?" At WCU, we have placed the value of student engagement and student learning as top priority, and as such, we defer all IP ownership to the client, for those IP items that are within the scope of the sponsored project. For example, at the completion of the cervical collar project, we delivered all design drawings, a functional prototype, and a complete Bill of Material to the Sponsor. In that case, as with many capstone projects with "discovery" content, the entire student team and the faculty mentor were included as co-inventors in the provisional patent application. This approach may be a non-starter for many universities with a significant Technology Transfer Office, but our experience has shown that the IP position for the university may be easily negotiated to satisfy both parties, provided the definitions are clear and there is a win-win outcome (as opposed to a standard "flat-rate" university policy on IP sharing).

4. Conclusion. We presented a model for executing multidisciplinary STEM/STEAM Capstone Projects for industry sponsors. WCU just completed its second year of these projects, based out of the College of Engineering, integrating student expertise from business, and health and human sciences. Last year, for the first time, we completed a project that integrated students from engineering and interior design. This year we completed definition of a joint project with engineering, business and history, which will launch later this year. We have demonstrated that potential barriers, such as accreditation, course credit, and faculty service are easily overcome with a collective effort to provide unique multidisciplinary learning and experience for our students that reflect what they will encounter in their careers. All contracting and invoicing for our projects is managed

out of a single office. In our case, it is the Rapid Center, which is equipped to execute external projects for industry partners. While this is an optimal solution for WCU, a similar management model could be easily executed from a university Technology Transfer Office. The key to a successful program is to have a large pool of faculty, deans, and other academic leaders that fully-embrace this unique student experience.

5. Acknowledgements. A special thanks to the faculty and staff of WCU, our long list dedicated industry partners, and the motivated students of WCU for making this initiative successful.

6. References

[1] Thomas, John W. "A review of research on project-based learning." The Autodesk Foundation (2000).
[2] Western Carolina University Project-Based Learning in Engineering, http://www.wcu.edu/learn/departments-schools-colleges/cet/index.aspx
[3] PMI FS-PMBOK-2013; A Guide to the Project Management Body of Knowledge; Project Management Institute.
[4] Directorate of Defense Trade Controls, International Traffic in Arms Regulations. Official Version (2007)
[5] Patterson D., Encouraging and assisting faculty incorporation of innovative classroom technologies. ACM Press (459041):79-81 (2004).

About the Author. Patrick Gardner, Ph.D. is Director for the Rapid Center and a distinguished professor in the College of Engineering and Technology at Western Carolina University. A retired Lieutenant Colonel, United States Air Force, Dr. Gardner has led large product development teams for government agencies and for industry. He has been at WCU for 10 years. In addition to providing engineering services to over 100 clients per year, Dr. Gardner directs and teaches the engineering capstone program, which now spans across the WCU campus and includes international partnerships with universities and companies.