AC 2011-204: FACILITATING STUDENT PROFESSIONAL READINESS THROUGH INDUSTRY SPONSORED SENIOR CAPSTONE PROJECTS

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Facilitating Student Professional Readiness through Industry Sponsored Senior Capstone Projects

Background

Western Carolina University (WCU), a regional comprehensive institution founded in 1889 with a distinguished history of teaching and learning for western North Carolina has begun the process of alignment with a new focus on innovation. WCU has launched an initiative to engage the resources of the university, its faculty, students, and facilities in the economic growth of the region. At a regional summit held at Cullowhee, NC in February 2003, the university was asked to explore engagement in non-traditional and creative ways[1]. Since that time, numerous initiatives have been launched to stimulate this engagement in new product development, in broadband communications, in adaptive devices, and in rapid prototyping[2]. The conditions are primed for innovative initiatives to convert this enthusiasm into reality. The Center for Rapid Product Realization, (CRPR) and the Department of Engineering and Technology have played a leading role in this engagement initiative. The CRPR was created to form a bridge and connect the resources of the Department of Engineering and Technology and the Kimmel School to the external community. Furthermore, a new capstone curricular sequence was developed, which combines project management, new product development, and interdisciplinary student teams. Our purpose was to produce engineering and technology graduates who are open to the injection of new ideas, comfortable in an environment that will nurture new product ideas from diverse disciplines and can mature promising ideas into actual business propositions.

FIGURE. 1

____________ IS IN THE SOUTHERN MOST EXTENSION OF RURAL APPALACHIA.

Regional context

The western North Carolina region is made up of the 23 western-most counties of North Carolina (shown in red in figure 1). This region is larger than eight U.S. states and is approximately the size of Maryland. The demographics of the region are largely rural with a rural population of almost 60% as compared to the entire state ratio of 39.8%. North Carolina ranks the highest in rural population among the twenty most populous U.S. states. Western North Carolina has a rich history in manufacturing — primarily furniture, textiles, and paper. Over the past 20 years, however, and, specifically in the earlier 2001-02 economic slowdown, these industries have been decimated, losing jobs to off-shore-competition and changing market conditions. Sixty nine percent (69%) of textile industry layoffs in 2001-02 occurred in rural North Carolina communities[3]. In the great recession of 2008, employment erosion continues to occur. The manufacturing base of the region is predominantly small businesses and manufacturing units. With that situation comes the long list of challenges that face rural regions including lagging infrastructure, isolation by distance, and weak economic competitiveness. The North Carolina Board of Science and Technology, in its "Tracking Innovation: The North Carolina Innovation Index" reports for 2000 and 2003, recognized that North Carolina needs to strengthen the training of its citizens, particularly its new graduates, for the knowledge-based economy and needs to enhance intellectual property and technology transfer in the marketplace[4]. The need for innovative and adaptable engineers is more pronounced in today's struggling economy.

The Department of Engineering and Technology at Western Carolina University

The Department of Engineering and Technology at WCU is comprised of the Electrical Engineering, Electrical and Computer Engineering Technology, and the Engineering Technology Programs with approximately 300 majors. Traditional lectures are complimented through hands-on laboratories for most subject areas where the design, build, and test model may be used to reinforce theory. In an effort to strengthen program outcomes and make the learning experience more relevant to industry practices, the department restructured the senior capstone courses in 2008 by partnering with the Center for Rapid Product Realization and using interdisciplinary project teams that engage the local region.

The Center for Rapid Product Realization at Western Carolina University

The mission for the Center for Rapid Product Realization is to match the Department of Engineering and Technology's expertise and resources to Western North Carolina's needs by forming effective partnerships to grow the region's economy, by assisting in generating value creating jobs and by improving the quality of life for its people. The Center is known and respected throughout the region as an innovative, can-do partner and as the primary resource for technical assistance and technology transfer for government, business and industry officials with local economic growth and job creation responsibilities. The formation and facilitation of multi-disciplinary partnerships will be a hallmark of the Center. The Center will concentrate on two primary goals: economic development and engaged learning.

The programs of the CRPR closely support the goals of economic development and engaged learning and are tightly aligned with the strengths of the Department of Engineering and Technology. The central theme that links the technical expertise with the four technical thrust areas is the ability to rapid convert ideas, concepts and processes into productive reality for Western North Carolina. Currently, these areas include opto-electronics, adaptive technologies, concept to manufacturing (including rapid prototyping and reverse engineering), intelligent sensor systems and most recently gas turbine technology. The technical thrusts are coupled and fully integrated with the instructional programs of the Department. Many of these areas have a multi-disciplinary character and this is particularly evident for adaptive technology where the collaboration with special education and physical therapy has been very beneficial.

Pedagogical approach

It has been well established that creativity, team working, leadership, problem solving, inter-disciplinary teaming, and project management have become essential skills if these engineering and technology students are to remain in high-demand and be globally competitive [5]. These critical skills, and particularly project management skills, are essential for the Department of Engineering and Technology's programs, which have adopted the project based learning (PBL) approach. PBL consists of complex tasks and challenging questions or problems that stimulate the students' problem solving, decision making, investigative skills, and reflection[6]. PBL provides a learning environment for the students and promotes learning through investigation and research[7]. Research suggests that the PBL learning experience tends to have a stronger long term positive influence on the students[8]. Accordingly, real-world research questions and problems are great candidates for PBL projects. The students have to think originally and creatively to come up with the solutions to these real-world open-ended questions and problems driving students to encounter the central concepts and principles of the subject hands-on.

For all the Department of Engineering and Technology's programs, a full two-semester two course senior capstone project sequence in the B.S. degree has been established and geared toward new product development. The capstone course sequence is multi-disciplinary where all three curricula, engineering technology, electrical and computer engineering technology and electrical engineering, are combined into one class. All projects must address new problems so that it will draw the students out of their comfort zone consistent with the department's goal of producing graduates capable of self directed learning. The text chosen for the two course sequence is entitled Winning at New Products[9]. The first capstone course in the sequence is a 3 hour credit course, comprised of a 2 hour lecture and a 2 hour lab block, and the second capstone course is also 3 credit hour course comprised of a 1 hour lecture and a 4 hour laboratory. Aside from class/laboratory time, faculty and industry mentors assigned to each team spend 1 to 4 contact hours per week guiding the students and projects.

The capstone project is a team activity with the team size varying from 2-4 students. The authors have observed that more than four on the team is difficult to manage and keep all members contributing to the effort. Several techniques have been used for the creation of the teams including self selection, assignment by common project interest and assignment by mixing high and low GPA. Problems and successes have been observed in all the approaches and at this time no technique has been demonstrated to be superior. The most unpopular approach with the students, but the one that has the highest fidelity with the real world, has been the assignment of teams by the instructor. The "best" results in our program have been a balance of instructor assignment and self selection through common interest in a specific project. Students select and prioritize the project topics that they prefer and the instructor then matches and forms teams based on that selection. In the coming classes, the authors are planning to use the "Teammaker" interview survey provided in the Comprehensive Assessment of Team Member Effectiveness tool (CATME) to assist in forming team based on project preference. This survey gathers information on the individuals themselves and the constraints on team participation. The survey information which can be customized for the particular class includes gender, race, GPA, class year, major, off campus/on campus housing, skills, preferred team role, schedule, commute, and employment[10]. It is up to the instructor to create selection algorithm utilizing these factors.

Applying stage-gate structure to engineering capstone projects

The well known Stage/Gate product development process is applied to all the projects[11]. Project management tools such as work breakdown structures (WBS), Gantt charting, scheduling and quantitative analysis of alternatives (AOA) are introduced and applied by the students in the first course in the sequence, which also spans the project proposal phase of the senior project. The first and second semester are linked through this unified series of stages and gates. Each gate has a set of deliverables and criteria for measuring success. The six-gate structure is shown illustratively in Figure 2. The six gates are respectively:

- GATE 1 Proposal;
- GATE 2 Conceptual Design;
- GATE 3 Preliminary Design Review;
- GATE 4 Critical Design Review;
- GATE 5 Release to Test; and
- GATE 6 Final Review.

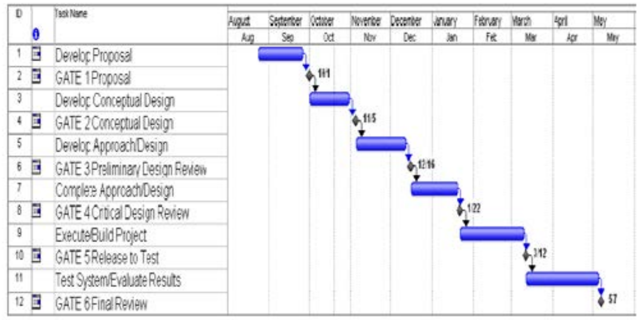

FIGURE. 2
TYPICAL TIMELINE FOR SENIOR CAPSTONE DESIGN PROJECTS

Deliverables for Capstone Project Gates	
First Semester	**Second Semester**
Gate 1 Proposal	**Gate 4 Critical Design Review**
Problem Statement/Context for Project	Design Documentation Package
Product Requirements	BOM and Procurement completed
Team Charter and Capabilities	Failure Modes and Effects Analysis Completed
WBS and Schedule for Conceptual Design Phase	WBS and Schedule for Project Completion
10 min Presentation plus Project Report	I hour Detailed Review plus Project Report
Gate 2 Conceptual Design	**Gate 5 Release to Test**
Refinement of Requirements	Updated Schedule
Three Conceptual Designs	Prototype Completed,
WBS and Schedule for Design Phase	As built Documentation
Budget	Test Plan finalized
I hour Detailed Review plus Project Report	Show Me Review plus Project Report
Gate 3 Preliminary Design Review	**Gate 6 Project Completion**
Design Progress	Testing Report
Long Lead Items	Design Documentation Package
Updated Schedule	Modifications completed
Poster Session plus Project Report	Final Project Presentations to External Reviewers

FIGURE 3
WRITTEN AND ORAL DELIVERABLES ARE REQUIRED AT EACH GATE.

The typical timeline for the two course sequence is shown in figure 2. While the stages and gates are depicted in clean, distinct steps, this depiction hides the normal iterative process that most design projects experience particularly given the build-in open-ended nature of these projects. The deliverables for each of the six gates are shown in Figure 3.

At the beginning of the first semester of this two course sequence, all the students are provided a catalog of projects proposed by the local industry partners. Potential projects have been solicited from industry and carefully triaged. To be suitable for senior capstone projects, the projects must:

- Be open ended requiring evaluation of multiple solutions
- Be complex and challenging requiring innovation, out of the box thinking,
- Be on subjects just beyond their present courses, requiring self directed learning
- Have sufficient scope that would require a team approach

Only those projects that meet these requirements are included in the catalog.

Students are asked to select their five top project choices from which teams are formed. In the 2009-2010 class, 24 projects were offered and 15 projects were taken on by student teams. In addition to the student members, each team is provided faculty mentors as well as an industry mentor to guide the activities.

Gate 1 Proposal Review: The focus of Gate 1 is to ensure that the team understands the problem that they are addressing. As a result the most critical deliverable for Gate 1 is the requirements matrix. The teams are encouraged to visit their customers and initiate regular communication schedules for the project. At Gate 1, the teams will formulate and propose the first WBS/Schedule for the project. In order to facilitate the learning process, the teams are only asked to breakdown and schedule the conceptual design stage. Concurrent tasks are encouraged. Important dimensions of the conceptual phase are 1) researching of existing products and solutions and 2) investigative experimentation. Trials with conceptual ideas and handmade artifacts are important tools for concept development.

Gate 2: Conceptual Design Review: It has been our experience that students typically gravitate to the first solutions that seems to fit. Later in the development the students are unwilling or unable to let the approach go despite the discovery of major flaws. To avoid this situation, the teams are required at Gate 2 to present three (3) designs that meet all the design requirements. Subsequently in the design phase they will be required to down-select using formal analysis of alternative (AOA) tools.

The review process in the series of gates has been selected to both meet the needs of the projects and give the students experience in a variety of review formats. At Gate 2, the review format is an hour long, detailed interactive review of the project. This style will be repeated at Gate 4 as well by request of the students who found that this interactive style of review was highly beneficial to the team.

Gate 3 Preliminary Design Review: The detailed design phase includes both Gate 3 and Gate 4. The role of Gate 3 is primarily to monitor progress and ensure that materials and components that require long delivery times are on order prior to the semester break.

Gate 4 Critical Design Review: This is the most critical of all the reviews. The next stage is fabrication and construction and, if the design is weak or incomplete, the next stage of fabrication will be very difficult. To uncover flaws in the design, the team is required to complete a failure modes and effects analysis (FMEA). This FMEA should have precipitated, during the design process, a critical examination of design aspects to avoid serious design failures. The interactive review process facilitates a thorough exploration of the design.

Gate 5 Release to Test: The fabrication stage is intended to produce a prototype. Along the way, design changes are inevitable. The team is required to maintain an as-built file folder to document the build. The teams are encouraged to incorporate components and subassembly testing into their fabrication process. However one of the deliverables at the end of the fabrication stage is a written test plan to be followed in the final testing phase. The testing plan includes in process testing, internal laboratory testing and final field testing. If the testing includes the use of human subjects, the testing plan must be review and approved by the WCU internal review board (IRB).

Gate 6 Final Project Review: The final review for the 8 month senior capstone project is the final wrap up of the documentation, test results and often modifications to resolve issues revealed through the testing.

Presentation methods for each gate and the final project include several venues form formal presentations in front of students, faculty, and industry partners; poster sessions; undergraduate exposition venues at ___, and publishing a scholarly paper at the National Conference on Undergraduate Research.

Assessment and grading

The grading system for the two semesters has three components: review, documentation, and participation. Each review, 3 in total, is awarded 25% of the grade. This 25% is based on rubrics filled out by mentors and faculty, on Gate project reports and on a peer to peer assessment of contribution using the web based CATME assessment tools[12]. The student has access to his/her CATME evaluation immediately after the survey is completed and is able to make adjustments as indicated by the survey. In addition the CATME tool provides the faculty member insight into problems that are occurring within the teams which allow the faculty member to take corrective action[13].

Each student is required to maintain a personal project logbook. This logbook simulated the traditional notebooks that engineers are often required to maintain in industry for intellectual property management. Each entry is dated, written in ink and contains class notes, team meeting minutes, action items from meetings, design sketches and other project information. At each gate, the logbook is reviewed and awarded 5% of the final grade for a total of 15%.

Finally 10% of the grade is awarded based on class participation and homework. Several individual homework activities were assigned and graded. For example students were asked to create a work breakdown structure, task relationship and schedule for a family celebration or party. A second example was to perform a formal trade study on the purchase of a vehicle. Students have many opportunities to volunteer to show their solutions and team documentation in class.

Project examples

In four years, thirty five (35) projects have been initiated. The number of industry sponsored projects has increased from 16% to 87%.

The projects for academic year 2009-2010 included the following titles and descriptions:

LED Lighting System to Assist Prostate Cancer Treatment (Image 1): Brachy therapy treats cancerous prostate tissue by implanting radioactive seeds into the prostate. Brachy therapy is minimally invasive and is very effective. Current method of seed implantation required verbal communication between the medical physicist and the physician during the insertion of the radioactive seeds and is susceptible to error due to verbal miscommunication and poor lighting. A student team started the development of a disposable LED lighting system and developed software to connect physician treatment plan to seed implantation. A second team is improving the design by making the system wireless and battery powered.

Image 1

Total Knee Replacement Rehabilitation Device (Image 2): The project sought to develop a device for home use to assist the patient in achieving full range of motion following a total knee replacement operation (see figure 4). Immediately following the surgery, scar tissue forms around the new knee components. To prevent this scarring to freeze the knee and limit the range of motion and flexibility, it is necessary to stretch the knee several times a day. No device exists to assist the patient in this exercise and several student teams working with an orthopedic surgeon developed a low cost device to assist the patient. Patent disclosures have been submitted including the students as inventors.

Image 2

Carolina Rehabilitation Inc. (Image 3): People with quadriplegic limitation and leg-disabilities need a rugged wheelchair for sports activities. Working in collaboration with Carolina Rehab., the project sought to re-design, build, and test an improved wheelchair for playing rugby.

Image 3

Image 4

Wake Forest (Image 4): The purpose of this project was to design and build a prototype mannequin with appropriate mass, geometry, tissue stiffness, and joint stiffness properties to be used for weight shifting and patient transfer simulations (including “oozing wounds”).

Kimberly-Clark: This project sought to develop and test RS View control panels for several operations within the facility.

MT&T: This project sought to design, build, and test a head tracking system for use in proton radiation therapy.

Image 5

Coast Guard (Image 5): The purpose of this project was to design and build a replacement structure and apparatus for the HU25 jet engines for display models to be placed at several bases

Image 6

Caterpillar Inc. (Image 6): The purpose of this project was to design, build, and test a seal handling apparatus with the goal of reducing work related injuries.

Image 7

FLS Energy (Image 7): The purpose of this project was to design, build, and test a solar apparatus producing water temps. at the mid-level (350 degrees F) for use in industrial processes (food production).

Image 8

MT&T (Image 8): This project sought to design, build, and test a head restraint system for use in proton radiation therapy

Several non-industry related projects were completed in 2009-2010 including a SWAT monitoring system, research in meta-materials, bee detecting apparatus, and a wireless BTU meter.

The subjects for academic year 2010-2011 include the following titles:

- Seal Face Protection and Packaging System---Caterpillar Precision Seals
- Metal Seal Inspection System ----Caterpillar Precision Seals
- Solar Thermal Controller Communication System ---FLS Energy, Inc.
- Improved Solar Box Heat Collector----FLS Energy, Inc.
- 360 degree Panorama Viewing with Acoustic Queuing----US Army Special Operation Command/Fort Bragg
- Improved Collapsible Litter for Transporting Wounded---US Army Special Operation Command/Fort Bragg
- Automated “Poking” of Biomedical Mandrels---Curtis Wright (Shelby, NC)
- 737/777 Actuator Test System----Curtis Wright (Shelby, NC)
- Physical world system simulation using a Computing Cluster---Western Carolina University
- System for Putting on Leg Compression Garment---Siskin Hospital Lymphedema Clinic
- Affordable MANUAL Handicapped Assist Mobility Device---Technovashun Chapel Hill, NC
- Battery Powered Wireless Brachy Lighting System---Shands Medical Center
- Powered torque wrench or Air Ratchet Wrench with Integrated Electronic Torque Wrench----Snap-On, Murphy, NC
- A Compressor Cascade Wind Tunnel---Edmonds Consulting Corporation
- Design and build a Solar Tree for the WCU Campus----Western Carolina University

Conclusion

The creation of a two semester interdisciplinary senior capstone course integrated with project management and product design has developed into a successful course structure. The Department of Engineering and Technology has benefited from The Rapid Center playing a key role in soliciting and acquiring enthusiastic industry support with 86% of the projects receiving sponsorship and industry mentors. Additionally, the co-mingling of disciplines, electrical, mechanical and computer engineering has set the stage for more challenging interdisciplinary capstone projects.

Student feedback has been mostly positive. Students have indicated through pre-post surveys that they feel more prepared for working in teams, handling conflict resolution, managing large projects, and giving presentations using a variety of methods and mediums. Students did indicate that the project required too much time and effort to complete given the short time frame. Additionally, several students indicated that their teammates did not “pull their load.”

Industry/customer feedback was mostly positive. Several strengths were stated and recorded in the post-project session with the sponsors. The sponsors felt strongly that the student had a real problem solving experience and they liked the level of engagement they were able to attain during the course of the projects. They felt strongly that the students really understood the design process and understood the concept of the problem they were tasked with solving. They observed the synergy display by the interdisciplinary interaction between the students. Finally, they praised the process as an excellent resource for customers/industry with time/resource constraints.

Several weaknesses were revealed from the industry/customer post-session. Many felt the scale and complexity of the projects varied greatly. Additionally, several witnessed individual team members taking control over the poster sessions and "taking all the credit for the work." Several industry/customers expressed the need for more pure creative-type projects and those that are student derived. Finally, they felt that the student teams did not engage them often enough throughout the process.

Several important lessons were learned from the projects conducted in 2009/2010. The students need more time performing project task where the project planning instruction is presented subsequent to the capstone courses. The department is in the process of implementing a vertically integrated PBL curriculum to address this need. Additionally, the "soft skills" learning that have been previously presented during the capstone sequence will now be delivered in the PBL curriculum. We have learned that faculty mentors are key role players in achieving success with the project in terms of meeting the learning outcomes. The faculty member has to develop a balance between meeting the needs of the customer, a completed product, and the experimental learning that must take place over the course of the project. Finally, student teams who engage the customer frequently throughout the progression of the project meet the requirements of the project more frequently. The 2010-2011 capstone year now requires faculty and industry mentors to meet one time per week to discuss the projects' progression. Overall, the 2009-2010 capstone sequence was a success for all involved. The 2010-2011 projects are underway and each team has completed their conceptual design reviews. During the conceptual design review, the faculty mentors perceived an increase in the quality of student work as compared to 2009-2010.

Bibliography

1. Western Carolina University. (2003). *A Regional Summit: Meeting Western North Carolina's Needs through Higher Education.* Retrieved May 18, 2005 from http://www.wcu.edu/chancellor/Presentations/regional%20summit.htm
2. Western Carolina University. (2010) Engagement at Western Carolina University. http://www.wcu.edu/5179.asp
3. Sorien K. Schmidt Elizabeth A. Jordan. (2003). Working Hard Is Still Not Enough. North Carolina Justice and Community Development Center. May,2003
4. North Carolina Board of Science and Technology. (2003). *Tracking innovation: North Carolina innovation index 2003. http://www.ncscienceandtechnology.com/*
5. Council on Competitiveness. (2004). *Innovate America.* http://www.compete.org/ pdf/NII_Final_Report.pdf
6. Barrows, H. S. (1986). A Taxonomy of Problem Based Learning Methods. Medical Education, Vo. 20, 1986, pp. 481-486.
7. Krajcik, J., Czerniak, C. & Berger, C.: 1999, Teaching Science: A Project-Based Approach, McGraw-Hill College, New York
8. Hill A. M.: 1998, 'Problem Solving in Real-Life Contexts: Alternatives for Design in Technology Education', International Journal of Technology and Design Education 8(3), 203–220.
9. Cooper, Robert G., Winning at New Products, Third edition, Perseus (2001)

10. Ohland, Matthew W., Pomeranz, Hal R. and Feinstein, Harlan W., (2006), The Comprehensive Assessment of Team Member Effectiveness: A New Peer Evaluation Instrument, 2006 ASEE Annual Conference, Chicago, IL, June 2006.
11. Meredith, Jack R. and Mantel, Samuel J. Jr., Project Management: A Managerial Approach, Sixth Edition. Wiley (2003).
12. Student Assessment of Learning Gains tools are available at http://www.salgsite.org.
13. Bonilla, C. and Perry L., "Evaluating Effect of First Year Engineering Teams' Performance using the Strength Deployment Inventory (SDI) Assessment Tool," 2008 ASEE Annual Conference, Pittsburgh, PA, June 2008.