Teaching Engineering Project Management via Capstone Designs that Develop a Viable Product

Don Bowie P.E., Aurasen Limited

Don Bowie is a Systems Engineer with an extensive background in engineering design and management, labor relations, and various academic positions. His undergraduate degree is in Electrical Engineering from the University of Illinois, with a Masters in Engineering from Seattle University. Mr. Bowie is an honors graduate from The Executive Program at the Darden Graduate School of Business Administration, University of Virginia. His engineering and management background spans four decades in Aerospace Projects which includes creating computerized engineering design tools, rocket orbital placement of telecommunications satellites, and the design and building of large-capacity electrical-generating wind turbines. His labor relations experience includes Vice President of the United States' largest professional/technical bargaining unit recognized by the Labor Relations Board. Don's academic career involves educational assignments which includes teaching and developing several engineering and business related courses as a University Adjunct Professor, plus a multi-year tenure as an Affiliate Professor at Seattle Pacific University. Mr. Bowie is presently the CEO of a technical entrepreneurial start-up corporation which has sponsored and participated in six Engineering Capstone Projects at California Baptist University. Don has had two United States' patents issued plus he was the primary author for three peer-reviewed academic papers which were published and presented at National Conferences.

Dr. Xuping Xu, California Baptist University

Dr. Xuping Xu is currently professor and chair of the Department of Electrical and Computer Engineering at California Baptist University. He received B.Sc. degrees in electrical engineering and applied mathematics from Shanghai Jiao Tong University, Shanghai, China, in 1995. He received M.Sc. degrees in electrical engineering and applied mathematics, and the Ph.D. degree in electrical engineering from the University of Notre Dame, Notre Dame, IN, in 1998, 1999, and 2001, respectively. In 2008, Dr. Xu joined the College of Engineering at California Baptist University. Between 2001 and 2008, he was an assistant professor and subsequently an associate professor in the Department of Electrical, Computer and Software Engineering at Penn State Erie, Erie, PA. His research interests include systems and control, hybrid and embedded systems, digital design, software/hardware enabled control applications, algorithms and optimization. He has published 18 journal papers, 38 conference papers, and 4 book reviews in the above areas. Since 2008, Dr. Xu has been serving as the assessment coordinator of the College of Engineering. He is a senior member of the IEEE and has been an associate editor on the Conference Editorial Board of the IEEE Control Systems Society. He also actively serves as a reviewer for a number of journals and conferences.

Dr. Anthony L Donaldson, California Baptist University

Dr. Donaldson is the founding dean of the CBU College of Engineering. Under his leadership the program started in the fall of 2007 with one additional faculty member, 53 students and 4 majors (BS CE, BS ECE, BS E, BS ME) and has grown into a college with four departments, twenty one faculty with PhD's, and 437 undergraduate engineering students studying 8 Majors. Dr. Donaldson received his BS, MS and PhD in EE from Texas Tech University where his research was in the Pulsed Power area. He has published more than 70 conference or refereed journal articles in a wide variety of fields. His current interests are in engineering education with an emphasis on interactions with industry.

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Abstract

Engineering Project Management is the orchestration of a plethora of disciplines to design a unique technical product. This paper describes the multiyear, multidisciplinary, interdisciplinary Capstone Projects that designed, built and tested a medical device to assist hearing impaired individuals. This effort was accomplished by two of the accredited Departments in a College of Engineering of a midsized private university by reaching out to the university's other colleges, to industry and to product-using practitioners – and embracing the mutually beneficial relationships therein.

The paper reports on the sequence of Capstone Projects that designed an engineering product for a small entrepreneurial corporation. This product, a medical device to assist hearing impaired individuals, is presently involved in a Capstone Project which is preparing the units for Clinical Testing. Integration of the Engineering College's multidisciplinary electronic, software and mechanical design disciplines developed the design. The engineering corporation sponsored an internship for project feasibility. Subsequently the corporation sponsored three Capstone Teams, in the 2011/2011academic year, which built and designed a proof-of-concept operational unit. A subsequent sponsorship of two Capstone Teams in 2012/2013 produced an engineering prototype. Presently a single five-student-member Capstone Team is preparing two functional units for Clinical Testing. An audiologist from a local medical clinic has provided direct mentoring and patient testing support. The paper also describes the interdisciplinary partnering that was undertaken with the University's School of Nursing and The School of Business.

Industry and product-provider representatives were present at appropriate times and provided real-time feedback. The representatives were also present at the student presentations; which included concept design reviews, detailed design reviews, verification readiness reviews and a final presentation; and provided both real-time and written feedback. This process of tracking/critiquing/mentoring, and its effectiveness, is presented from the overseeing participants' viewpoint – effectiveness in measurements that matter to each involved party.

The pedagogical approach was to conduct a capstone project as near as possible as to an engineering project as conducted in industry. The intent was not to fully expect the students to be able to conduct an engineering project, but rather to make the transition from school to industry less of a major transition. By using the development of a potential viable product as the item to be developed, the concept of following a customer's requirements was introduced. The outcome was two fold: to have the student work with "the customer" by working with a corporate executive and with a front-line provider; and to attempt to satisfy those two customers. Assessment of the learning obtained were based both on grading of the assigned documents and presentations, plus the level of satisfaction-feedback received from the customers.

End of abstract

Pro-active Involvement:

Similar to an engineering project in industry, a successful Capstone Project only can be as effective the least-motivated directly-involved party. The Capstone Project in this case study has consisted of six multi-member student teams during the last three years to develop a user-programmable hearing aid system. There was significant "outside" professional involvement in this multiyear/multidisciplinary/interdisciplinary undertaking. The multidisciplinary leadership team consisted of members from the academic, corporate and consumer-provider areas. At the student level the multidisciplinary effort consisted of the combination of mechanical, electric and software teams. At the interdisciplinary level teaming with other Schools/Colleges within the University was entered into.

The Beginning:

Early in 2011 the Dean of the College of Engineering at California Baptist University (CBU) – a private Christian university with its main campus in Riverside, California and with an enrollment of over 7000 students – informed his Strategic Advisory Board that there were several of his engineering students that needed summer internships to fulfill a mandatory requirement for graduation. (The Strategic Advisory Board consists of engineering-related industry Chief Executive Officers (CEOs) and company Presidents who provide support and feedback to the Dean.) One of the responses was from the CEO of a small entrepreneurial start-up corporation that agreed to employ a student from the Electrical and Computer Engineering Department (ECE) to create a feasibility study for a new product the company was interested in exploring. The summer intern created a simulation of the considered product and proved that, yes indeed, the concept was feasible.

The Engineering Dean, Anthony Donaldson, PhD, and the CEO of Aurasen Limited, Donald Bowie, agreed that they would pool their resources and be the initiating innovators to develop a proof-of-concept engineering model of the proposed commercial product. The model would be developed with the corporation sponsoring a three team Capstone Project for the 2011/2012 school year. The University was to provide the pedagogical aspects and the corporation would provide technical project management support. Additionally, a practicing professional Clinical Audiologist, Donna Eskwitt, PhD, from a large local medical clinic volunteered to provide a user's perspective.

The People:

At the professional leadership level the Capstone undertaking involved individuals from Academia, Industry and Clinical: The College of Engineering Dean, Dr. Donaldson; the CEO of a for-profit Corporation, Mr. Bowie; and an Audiologist, Dr. Eskwitt, at a large local medical clinic. Each leader was committed to support the multi-task three-team Capstone Project. This leadership commitment included the personal active involvement of each of these three leaders.

The Dean assigned the Chair of the Electrical and Computer Engineering Department (ECE), Xuping Xu, PhD, and a Professor in the Mechanical Engineering Department (ME) to be the

Capstone faculty members. The CEO assigned his Chief Technical Officer (CTO) to be directly involved. The Audiologist elected to provide oversight directly. The three student teams consisted of mechanical (hardware design), electronics (circuitry design) and software (computer program development).

The Preparation:

A major strength of the undertaking was the expert direction and advice that each individual provided as the Project progressed. The academic individuals would create and develop the pedagogical implementation, emphasizing the student related technical and project management functions: including relevant lectures, class instruction and personal availability to the students. The corporate individuals were to emphasize the technical, financial and project management aspects from an industrial perspective. The audiologist would emphasize the "patient" aspects and User Interface (UI) considerations. The financial provisioning was modest as this project relied on the corporate and audiologist's voluntary time involvement. The corporation provided limited financial support for parts procurement.

The Capstone Project students (fourth year) had been introduced to project structure and development tools such as: Statement of Work (SOW), Requirement Specification, Work Breakdown Structure (WBS), Gantt Charts and Project Reviews (with major deliverables/milestones such as concept selection, conceptual design, detailed design, prototyping, testing and verification of readiness and the design review presentations which take place twice every semester). As is the practice in industry, a contractual agreement was signed by the Dean of Engineering and the Corporate CEO (the contractor and the customer). A non-disclosure agreement was signed between the Corporation and each involved professor and student. The system Requirements' Documents were signed by each student team, the ECE Chair, Dr. Xu, and the Corporate CEO. Progress milestone commitments were created and recorded. Action items were utilized. A balance of cost, quality and schedule was expected, acknowledging that a university's academic schedule cannot be violated. In accordance with the Corporation's normal employee policies, each student was requested to fill out a weekly time card documenting their effort expended, including task description and time expended on each task.

As part of the corporation's commitment, a corporate officer was to be in attendance at syllabus-scheduled reviews. Additionally, an interface, during class time, of pre-planned teleconferences between all the students and a corporation representative was to take place every week. The audiologist agreed to participate in design reviews and to invite student teams to her clinical office to view current hearing aid technologies, relevant programming issues and in responding to patient expectations.

The First Year Results, Lessons Learned and Corrective Actions:

The Capstone Project adhered to the aforementioned project management tools and corporate/audiologist support; however, a verified proof-of-concept unit was not completed. It was agreed by all parties to continue this hearing aid project as a 2012/2013 Capstone Project using the same basic project management tools and support. The following is a summary of

causes for that incompletion and the associated corrective changes that were implemented into the subsequent 2012/2013 Capstone Project. It is intended that these inputs will provide useful to others involved in engineering education.

It is understood that most of an engineering undergraduate student's time is spent on individual studies; whereas, on an Engineering Project teamwork is paramount. The military enforces teamwork through intimidation – not a good approach for advanced education. It is additionally understood that in the post-secondary-education environment the student is also the customer. In industry the individual is an employee who is expected to adhere to project objectives in return for financial remuneration. These differences illustrate a cultural chasm. This dilemma was addressed by acknowledging this inherent situation and diplomatically introducing the student to the chasm they will cross between graduation and employment. Also, it was decided to have only two teams in the second academic year to reduce required interfacing – a mechanical student team and an electrical/software team. Two high-profile entrepreneurs who possibly recognized this cultural chasm and voluntarily elected to terminate their undergraduate engineering studies in order to immediately pursue their careers are Bill Gates (Microsoft, in 1975) and Mark Zuckerberg (Facebook, in 2004).

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Along with involvement comes commitment. And commitment implies motivation and priority setting. For the students it is the commitment to manage the competition with other class assignments – assignments that are near term as opposed to "sliding" (delaying) Capstone Project scheduled milestones which can be "accomplished later." For the professors it's the commitment to re-vamp existing curriculums, plus providing class time for the corporate and provider individuals to allow all-student inter-action. For the corporation it's the commitment to devoting a portion of their time toward potential future product development at the expense of more near-term profit pursuits. For the product provider, it's the commitment to reduce their caseload in order to provide the time required for consulting sessions and reviews. A Corporate representative was given time by the faculty to meet with the students immediately after their reviews. The Corporation agreed to have an individual remain after the review presentations for subsequent student interfacing. The Audiologist volunteered to not accept patient appointments during student review periods so that review attendance would be accomplished.

An effort to bring an interdisciplinary element to the Capstone Projects was by partnering with the University's School of Nursing to investigate the possibility of Product Clinical Testing by using patients that the student nurses visited during their off-site clinical-training sessions. The School of Nursing agreed to spearhead Clinical Testing of the hearing aid product by including that effort with the normal medical evaluations conducted at their off-site medical-patient health-evaluation training. These field sessions are lead by faculty and accompanied by a graduate nursing student who is also a Registered Nurse. Although there was insufficient time to implement this cooperative effort, enthusiasm for such an endeavor was expressed by the Dean of Nursing and the Dean of Engineering. It was decided to implement this arrangement during the 2012/2013 Capstone Project. The school of Nursing anticipated that this interface would provide a student working experience with an electronic "medical device" that would be well beyond the normal blood draws, vital-sign measurements and blood glucose determinations.

Concern was expressed that it would be difficult for the 2012/2013 capstone students to "pick up the continuum" of the work accomplished by the 2011/2012 Capstone teams. To provide the students detailed product-specific technical support, two of the key 2011/2012 Capstone students accepted a non-monetary contract from the corporation to support the 2012/2013 Capstone Project. One of the 2011/2012 students is presently doing full-time graduate studies at another university and the other is employed full time in his chosen engineering profession. This commitment to assist the existing students is an excellent measure of the Capstone Project's success as it pertains to the students who participated in the initial Capstone Projects.

Emulating the corporation's normal employee policies, it was decided to henceforth have each student be requested to fill out a weekly time card documenting their effort expended (including daily task descriptions and time expended on each task). However, these records were not to be utilized for evaluation.

The Second Year Results, Lessons Learned and Corrective Actions:

The 2012/2013 Capstone effort provided two operational prototype units; however, these units did not complete verification testing. All parties (Academic, Corporate, and Audiologist) agreed that, because of the educational benefits the Capstone students were receiving, a 2013/2014 Capstone Project would be supported with the intent of accomplishing "Clinical Testing" of the two prototype products. Partly due to continued lack of sufficient interfacing between the two teams of the 2012/2013 Capstone Project, it was decided to only have one five-person team in the ongoing 2013/2014 Capstone Project.

It was realized that a teaming emphasis could best be promoted by having the corporate representative that interfaced with the students each week be a technical individual with extensive Project Management experience. The corporate CEO elected to personally undertake this responsibility. It was decided that the project management and intra-teaming would be enhanced by having the students contact the CEO each week during class time to discuss accomplishments. In addition, the CEO would personally visit the team, during class time, whenever a major milestone was due. To support this effort the ECE Chair agreed to provide two hours of class time during each of these on-site CEO meetings.

One of the reasons that verification testing was not completed in the 2012/2013 Capstone Project was because the University's School of Nursing was not allowed to use the engineering prototypes. The University's Legal Counsel insisted on liability insurance requirements that were unacceptable to the sponsoring corporation's legal counsel. Another agreement to consider Clinical testing of the prototype was developed for 2013/2014 – a plan that addressed the University's legal concerns. The supporting Audiologist agreed to oversee off-site Clinical Testing using volunteers from the Audiologist's own patient database. In addition the Engineering students would do basic human interface testing on volunteers that were within the University (Faculty, and students 18 years and older). As a prelude to this testing, the prototypes would be upgraded to address various technical issues that were observed during the previous two years.

A significant item that also delayed verification completion was the lack of "discipline" required for a long-term project effort. A final examination is not given for Capstone Projects; therefore, it was easy for the students to again fall into the "tomorrow syndrome" for an entire year, not just for a semester (or quarter). To address this issue it was decided that it would improve motivation to have an even closer milestone tracking to assure that "due-diligence" was being applied to each component of the project. Project Management depends on discipline and continued vigilance to make sure all aspects are being properly addressed, i.e. make sure it happens (Just Focus and Do It – JFDI).

It was decided that mandatory time card reporting should be hereafter employed, and including it as a component of the grading system, which would reduce discrepancies associated with the varying levels of effort provided by each student plus help provide an incentive to obtain the expected level of student effort. For example, if an individual in industry does not provide consistent time reporting there is the possibility that that person may not get fully paid. It was considered that a reward/penalty grade impact would be appropriate for Capstone Project students. Because time reporting had not been a factor in grading, it was often observed that significant discrepancies existed between efforts expended by the individual Capstone team members. (A minimum of nine hours per week per student was specified in the course syllabus.) The adherence to time card reporting ranged the full gambit: from unwavering detailed inputs each week to totally ignoring the request for time card submittal. However, an observed, but undocumented, correlation was noticed relative to each student's time card reporting: there was a basic direct relationship to a student's time card diligence and their observed respective pro-active commitment and motivation toward the project. The adherence to time card reporting and sufficient hours expended was made a component of the students grade for the 2013/2014 Capstone Project, and that grading component was incorporated into the class syllabus.

To allow access to lab facilities, so that student time expended could be maximized, the ECE Chair provided the Capstone Team dedicated lab space and equipment; accessible by the students 24/7. The Corporation provided additional unique hardware components to provide a backup for any malfunctioning or damaged parts. Both of these actions were "excuse-mitigation actions."

To further minimize "technical inertia", one of the contract individuals (2011/2012 students under corporate contract) would attend the reviews and each CEO visit – as their schedule allowed. In addition Skype interfacing would take place as required between the two contract individuals and the 2013/2014 student team, plus Saturday on-site tutorial working sessions would be undertaken as required. As may be expected, it was observed that these support actions were often exercised the Saturday immediately prior to the CEO arriving for a mayor milestone review.

To bring further interdisciplinary involvement, the College of Engineering Dean and the School of Business Dean agreed to bring the Capstone Project to the University's School of Business. Arrangements were made to tailor an existing Marketing Course to use the Engineering prototype as the item to be researched and investigated relative to its marketing potential. The resulting effort produced several marketing plans for the intended product. The marketing plans included domestic markets (Audiologists and e-commerce), foreign markets (Great Britain and

India) and a governmental medical-agency market (Veterans' Administration). Again, the corporate CEO and the Audiologist worked directly – including in-class time – with the business students. This undertaking was a definite success. As a result of this effort, an initial product introduction method was decided upon by the Corporate CEO. The ultimate measurement criterion for the success of the Marketing Class involvement was witnessed when the Corporate CEO provided personalized letters of appreciation to all the involved business students. The Business School used this exercise to introduce the business students to an actual potential future product offering, and the associated interfacing with the Corporate CEO and the product provider.

Individuals' Results to Date:

For those leaders and professionals involved there has been the sense of accomplishment in providing, to a future generation, an "on the job" use of the tools and procedures that the engineering students will utilize in their future professional engineering careers – an early introduction to the "industrial world." The metric that indicated this success is the ongoing corporate, provider and faculty support.

For the professors, they were able to provide the students with an "industrial" project experience. The corporation was provided a cost-effective proof-of-concept for a device that would probably never be otherwise pursued. And the Audiology provider received the ability to steer a new device toward improved efficacy for the benefit of potential hearing aid customers.

In industry, project management of the triad of schedule, cost and quality are very closely monitored; often via an attendance-mandatory weekly managers' Project Review Meeting. The company's Financial Department presents the budget/expenditure status (cost), the Engineering Department presents the requirement/development status (quality) and the Project Manager chairs a review of schedule/accomplishment status (schedule). On our capstone projects a budget limit is given the students with the students having to obtain company approval to overrun that cost figure. We found that the students were very conscientious in this area. When certain product operational requirements were found to be over-difficult for student accomplishment the company either revised the specific requirement or provided technical support.

A Gantt chart is the primary tool a corporation's Project Manager uses to track and adjust the schedule – with each reporting-manager directly responsible for their milestone accomplishments. This Gantt chart detailed review wasn't attempted because of the very significant time that is expended in the process; thereby, making such an implementation impractical for the professors who must oversee numerous Capstone projects simultaneously. We observed that the difficult decision to not utilize this key project-tool contributed to the students' "mañana malady" to procrastinate – they weren't held constantly accountable. Although the students had undertaken short projects throughout their engineering undergraduate studies, the Capstone project is unique in that the outcome hadn't been verified by previous classes, nor was it a "fun competition" with other teams doing the same project. However, we believe that the students did receive a good introduction to long term project operations where persistence and ongoing innovation are required – exactly what will be expected when the students graduate, and they become employees or entrepreneurs.

The Bottom Line:

You may ask: “How were you able to form a team of volunteer professionals willing to commit substantial time and their expertise in a university’s educational undertaking?” Possibly it’s altruism; possibly it’s a faith-based reason; possibly it’s the excitement of new product development; possibly it’s the ability to interface with the best and brightest of a succeeding generation; or possibility it’s for the potential of a benefit that each individual personally holds. Probably; however, it’s the same reason each of the readers of this paper is involved in engineering education: “The assignment is for you to fill in your own answer.”