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Vetting Industry Based Capstone Projects Considering Outcome Assessment Goals*

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One goal of capstone projects is that they simulate a challenging design experience similar to what is expected of a BS graduate engineer. Consequently industry originated capstone projects are very valuable since they are based on real world problems and technical challenges. Capstone projects are also a critical part of the assessment process for most engineering programs. The challenge arises in how to evaluate the potential of an industry based project in providing assessment information related to program learning outcomes. This paper provides an example of a vetting process used successfully to accomplish this complex evaluation of alternatives.

Keywords: assessment; capstone project; industry project

1. Introduction

The accreditation of engineering programs is guided by ABET, Inc. and generally stipulates conformance to program outcomes listed in the criteria documents [1]. These outcomes represent the characteristics demonstrated at the completion of the BS degree and provide the foundation for graduates to meet program objectives which are demonstrated in the work place during the engineering career. For many engineering programs, capstone projects are a critical part of the assessment process since they simulate a challenging design experience similar to what is expected of a BS graduate engineer [2] Consequently industry originated capstone projects are very valuable since they are based on real world problems and technical challenges [3]. An important issue in capstone project selection is how to evaluate the potential of an industry based project in providing information applicable to accreditation assessment. Since the capstone project is a vital part of many ABET assessment plans, high priority must be given to identifying projects that fit the assessment targets of a-k program outcomes as described in Table 1.

There is a wide and long developed history of research and studies related to methods, assessment, and effectiveness of capstone projects and related pedagogy. Todd et al. [4] provide a seminal work which examined the state of the art at that time and is frequently referenced as a foundation by more recent topical studies. Even at this early point in capstone project development, 64% of respondents indicated they were involved in some level of industry sponsored projects. Howe and Wilbarger [2] updated this seminal work and found that 71% of the respondents used capstone industry projects. Study of the selection process for capstone projects has also grown as a specific research focus over the last ten years. Little and King [5] examined differences in selection criteria between senior and freshmen projects and provided useful guidelines for industry sponsors. Similarly, Magelby et al. [6] studied industry capstone projects from a pro / con perspective and also examined guidelines for consideration by the sponsor.

A number of papers have also examined the issues of capstone project assessment and the critical role of capstones in the engineering curriculum. For example, McKenzie et al [7] studied assessment practices in capstone projects related to ABET criteria and also examined faculty opinions on assessment method effectiveness. From a larger program perspective, Shuman et al. [8] examined the issue of assessing the professional skills in the ABET a-k outcomes and examined how capstone projects can also integrate assessment across several of the ABET criteria.

A number of papers examined how capstone projects relate to ABET outcome assessment. For example, Davis et al. [9] examined a general framework for capstone assessment. Others examined specific outcomes. For example, Welch and McGinnis [10] presented an assessment protocol for considering teamwork related to outcomes attainment; Peretti et al., [11] consider the assessment process for communications within the capstone project; Wang, Fang and Johnson [12] explored assessment of lifelong learning via the capstone project. From a pedagogy view, Biney [13] describes the role of student documentation in ABET accreditation. Finally, Rizkalla, El-Sharkawy, and Salama [14] describe a selection process which examines pedagogical issues such as whether the project has sufficient time requirements for the team members.

In this capstone project literature, there is an

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Table 1. ABET Program Outcomes

Engineering programs must demonstrate that their students attain the following outcomes:

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

important and generally unstudied area: the issue of selection or vetting of capstone project alternatives from the perspective of assessment potential. Specifically, the issue of compatibility of projects with assessment needs has not been studied. This paper contributes to building the body of knowledge on selection of capstone projects. It presents an example of a vetting process used to accomplish this complex evaluation process with good success. The next sections examine this capstone project process and how projects are solicited, identified, and reviewed.

2. Capstone project process overview

The capstone project design experience is structured into a two-semester course sequence, ENGR 4010 and 4020. Each semester of these two credit courses is comprised of a one hour lecture and a two hour scheduled laboratory period. This mix assures all members of the team have an open hour to meet with the advisor and a two hour open time for student teams to meet with the industry client or each other. An additional expectation is that significant time is spent on the capstone design project outside these structured and specified times. The course was developed at the start of the program in 2004, based on faculty experience at other universities and from current literature such as Chang and Townsend [15] and Davis, et al. [9].

To ensure integration of engineering standards, realistic constraints, and close collaboration with the advisory board and regional industry, every project for the first four graduating classes has been industry sponsored and representative of the expectations these clients have for design performance of entry-level engineers. This emphasis on real projects promotes relationships between our regional technology base, our program, and our students. In addition, faculty are able to see first-hand the needs and expectations of local industry. This in turn allows the program to apply this experience to analyze how the curriculum courses provide the necessary foundation to meet industry needs in solving complex, yet entry-level, engineering design problems.

Our degree is not a traditional, discipline specific program. We offer a BS in engineering with concentrations and in general the curriculum is comprised of a common core of engineering courses (39 credits) which every graduate takes coupled with concentration courses (25 credits focused on biomedical, bioprocess, industrial and systems, and mechanical). Students typically choose a concentration at the end of sophomore year. An important program goal is that capstone projects demonstrate interdisciplinary technical skills and problem solving related to a number of ABET outcomes. Projects are identified using the internally developed, multi- tiered process described briefly below and illustrated in Fig. 1.

1. The first contact with the client is often made by our lead faculty member for industry outreach (Director, ECU Team Engineering). Once a potential project is identified, a brief abstract, or scope statement, is developed.
2. This abstract is circulated to the capstone project committee, which rates the project on the potential in meeting assessment outcome goals.
3. If the project receives positive evaluations from the capstone project committee, a faculty advisor is identified for the project. In general, the faculty advisor is selected based on identifying a fit between faculty interest and background and the requirements of the project. For example, a bio-processing related capstone project would typically involve a faculty member with background in that area.
4. The faculty advisor meets with the client to be sure there is a thorough and shared understanding of the scope and deliverables expected of the project. By the time the faculty advisor finalizes this common ground on project

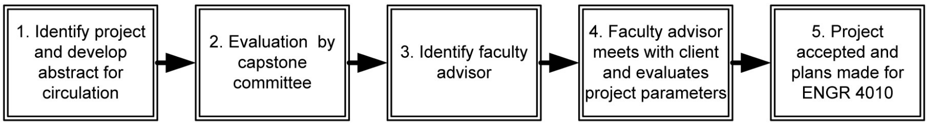

Fig. 1. Capstone Project Selection Process.

details, several iterative reviews have occurred to ensure the project is solid (i.e. substantial design content) and achievable. This process ensures that the faculty advisor understands the skills required from the students and issues the students will need to address.

5. This faculty member then becomes the advisor for this project for the ENGR 4010/4020 course sequence.

Evaluating the extent to which capstone projects align with program assessment criteria is a process step that occurs during the first two phases shown in Fig. 1 and is described further in the following sections.

2.1 Project solicitation and identification

The fall semester project identification process begins in the preceding January with a solicitation of potential clients. As the program has grown, we have been able to capitalize on the loyalty of previous capstone project sponsors so the first tier of solicitation notices focuses on previous capstone project participants. As an example of this long term relationship, our first project sponsor has provided one or two projects every solicitation cycle since the capstone project course's inception. The second round of solicitations occurs in February and is sent to Engineering Advisory Board members and engineering alumni. Again, the intent with this round is to build commitment to the program and understanding of the value of the capstone project experience as a good business decision. A final call for capstone projects, if needed, goes out in March to all industry contacts within the department's mailing database.

Sponsors proposing projects are asked to draft a simple abstract that briefly describes the project including final project deliverables, general constraints and identification of the sponsor's point of contact for the project. Proposals from sponsors must be finalized by May, since this is a convenient time to conduct a formal proposal review by the capstone project committee prior to the summer break. Although the workplace is dynamic, we have not had an issue with project cancellation over the summer. Table 2 provides an example of a first draft project scope proposed by an industrial client.

2.2 Assessment goals

To provide context for discussing the project evaluation and final selection process, this section identifies the assessment goals for the ENGR 4010–4020 sequence. The assessment plan for the capstone project course cuts across a wide range of outcomes. As an 'end of pipe line' quality control process, the goal is to examine many stand alone and integrated skills. Table 3 summarizes the assessment plan for the two semester capstone project sequence.

Table 3 indicates several important themes. First, the assessment plan relies heavily on student work samples along with input from the advisory board and the client for the project. Second, relative to ABET a-k outcomes, the project under consideration must present substantial opportunity for students to demonstrate capabilities in four outcome areas:

Table 2. Example of Project Scope Proposal

Project Title: Identification and Recommendations for Energy and Water Conservation.
This project is intended to help identify ways to better manage and control its loss of energy and water. This process focuses on two specific areas of conservation.
The first area is energy recovery through steam condensate return. Boiler analyses demonstrate a low amount of condensate return from the plant. The loss of condensate results in the use of more fuel to replace the energy lost. When condensate is not recovered, fresh make-up water is used to replace its loss. The use of fresh water results in higher fuel oil consumption to heat this water and more boiler chemicals to treat the fresh water. We would like to get recommendations for identifying, monitoring, and recovering these losses.
The second area is water conservation through better monitoring. Our water usage is higher than expected. All water used in the plant should be discharged to waste treatment or to the non-contact discharge point. Each area of the plant has a water supply and discharge. Understanding how much water each area is using will allow us to identify excessive usage. We would like to get recommendations for monitoring water usage in each area allowing us to identify excessive usage, thus reducing undesired water losses.
Identifying these losses for potential recovery will help us become a better environmental steward while saving money and resources.
Contact: Samuel XXX, Director of Operations, 252-111-0000, XXX, Inc., PO Box XXX, XXX Hill, NC 27000

Table 3. Capstone Project Assessment Summary

ENGR 4010 Senior Capstone Design Project I	Student Work Samples: • Design proposal demonstrating formulation of problem and recognition of constraints (Outcomes c and g) • Assignment showing understanding of professional ethical responsibilities (Outcome f) • Assignment showing recognition of societal issues in design (Outcome h) • Assignment showing awareness of continuing education resources (Outcome i) • Application showing knowledge of contemporary issues in the engineering profession (Outcome j) • Student Course Survey
ENGR 4020 Senior Capstone Design Project II	Student Work Samples: • Assignment showing awareness of continuing education resources (Outcome i) • Evaluation of Capstone Projects by Faculty and advisory board (Outcomes a, c, d, e, g, and k) • Student Course Survey

(c) an ability to design a system component or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
(d) an ability to function on a multi-disciplinary team.
(c) an ability to identify, formulate, and solve engineering problems.
(d) an understanding of professional and ethical responsibility.

Consequently, these considerations provide the foundation for the vetting process.

3. Project vetting

As noted in Fig. 1, once the proposals are received from the client, they are vetted by the department's Capstone Project Committee. This committee is comprised of a representative faculty member from each concentration (concentrations include: mechanical engineering, industrial and systems engineering, bio-process engineering and bio-medical engineering), the capstone design course(s) coordinator(s), the department chair and the Director, ECU Team Engineering, who has responsibility for acquiring capstone projects and leads industry outreach and liaison efforts.

During the committee's proposal review meeting, each project is reviewed individually with consideration given to matching projects to the goals and objectives of the concentrations represented in the rising class of juniors. Using a form listing the ABET Outcomes that are assessed via the capstone course, the capstone project committee considers each proposal on its individual merits relative to its ability to support evaluation of the list of outcomes. A sample form is included in Appendix A. Currently we do not weight the outcomes noted on the evaluation sheet since the resulting assessment information is used in a summative manner by our ABET assessment plan to determine in the aggregate whether we are meeting the specific outcome.

Primarily, the capstone project committee examines two questions for each proposal.

- How does the project proposal support each of the outcomes?
- What is needed to strengthen the proposal or how could it be improved to better meet assessment goals?

Members of the committee are asked to review the proposals relative to these questions and assign a numerical ranking to each outcome based on the perceived strength of the proposal. This step accomplishes two additional benefits for positive project outcomes:

1. First it forces faculty to consider specifically how the project would be executed along with the end product. This helps to identify a general framework for a focused scope which is a particular issue in the early drafts as evidenced by the example in Table 2 (which is very broad). Although we don't want to remove all complexity from scope development by the students, we want to assure that students begin this process with a reasonable boundary to the project so they do not struggle in developing a feasible charter/scope description.
2. Second, it promotes discussion of constraints and helps to identify issues necessary to discuss with the client to remove ambiguity in expectations and lack of clarity in the targeted outcomes. In most cases, one of the committee is assigned to further examine the project by visiting the client and further refining the scope and constraints to assure there are no major roadblocks and the scope can be accomplished in two semesters.

Forms are returned from the capstone project committee to the Director, ECU Team Engineering for compilation of evaluations and primarily to address, with the proposal sponsor, any items where more information might be needed prior to a committee discussion of the relative merits of each proposal. This objective approach gives every pro-

Table 4. Example of Revised Project Scope Proposal

Project Title: Identification and Recommendations for Water Conservation.
This project is intended to identify ways to manage and control water use. This process focuses on two specific areas.
The first area is examination and improvement of the water distribution system. In general, this first step will involve development and verification of piping diagrams and related points of use. Based on this information, a metering system will be designed to assure that monitoring of use and identification of waste can be completed as part of a water use monitoring system.
The second area is water conservation. Based on understanding of volumes and points of use, assure that all water used in the plant is discharged to waste treatment or to the non-contact discharge point. By understanding how much water each area is using, identify excessive usage and make recommendations for reducing undesired water losses.
Identifying these losses for potential recovery will help us become a better environmental steward while saving money and resources.
Contact: Samuel XXX, Director of Operations, 252-111-0000, XXX, Inc., PO Box XXX, XXX Hill, NC 27000

posal an opportunity for success. Finally, each proposal is discussed by the committee one more time and proposals meeting the assessment objectives with the highest compiled scores are selected for use in the fall term. Changes in scope can be significant compared to the starting point as the revised example from Table 2 to Table 4 shows. Relative to the steps in Fig. 1, the first two steps are complete at this point and the next section describes steps three and four.

3.1 Faculty project advisor

Steps three and four in Fig. 1 reflect an absolutely essential part of the project committee vetting process: integration into the scope and selection process of the faculty member who will be the project faculty advisor. This individual functions as the technical advisor and 'drill sergeant' for the project team over the two semesters of project completion. In general, selection of this key faculty member is the job of the department chair and this is done with consideration of factors such as teaching load and expertise in the area of the project.

Selection of the project advisor must be completed concurrently with the completion of the scope statement with the client since the advisor should:

- Verify the scope is technically appropriate and, the project can be completed in two semesters. A key part of this step is to identify the size and background of the student team. Projects often need a mix of concentration skills to represent the design areas required by the project. For example a recent biomedical sensor project required mechanical and biomedical student skills.
- Meet the key contact person of the project sponsor and develop a shared understanding of mutual responsibilities and project outcomes.

4. Assessment results

As we have described, the focus of this effort has been to better coordinate assessment criteria and project selection steps to assurance that the final project results will satisfy assessment needs. Assessment data, evaluating our results, have been collected annually, both at the end of the first semester of the two semester sequence and at the end of the second. Table 5 shows student survey data ('I am able to . . .') across the two semester sequence for the last two years. The table reflects student agreement that the capstone projects are meeting assessment requirements and this supports the effectiveness of the project selection process. Our ABET assessment plan currently does not look at the variation in student responses for our course surveys but we plan to monitor that in the future to determine if there is excessive variability in how the capstone project experience impacts student perceptions.

Similarly, the feedback from both industrial clients and advisory board assessors has been increasingly positive as we have continued to refine and improve the vetting process.

5. Summary

The vetting process described in this paper has been an effective tool to identify viable and productive capstone projects and develop a shared faculty vision on expectations for outcome assessment. From the perspective of students, industrial clients, and the advisory board, program performance on capstone projects continues to increase in ratings

Table 5. Student Survey Results (1 strongly disagree; 5 strongly agree)

Outcome	2009	2008
c) . . . design . . . to meet desired needs	4.06	4.19
d) . . . effective teamwork	4.17	4.44
e) . . . engineering problem solving.	4.19	Not assessed
f) . . . professional and ethical responsibility.	4.58	4.44

and in the quality of the final reports. The foundation for this increasing level of success is selecting capstone projects using an approach which links assessment outcomes with curricular needs and promotes an iterative process of project evaluation and selection.

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Appendix A: Example of Vetting Summary

2008 Capstone Project Evaluation Sheet ECU- Department of Engineering		
Evaluator: Kauffmann	Date: March 12, 2008	
Project Title: LED lighting assessment		
General comments: This project is a very good systems or engineering management design project. It focuses on developing a path forward for migration from HID or incandescent light fixtures to LED technology. Project requires students to apply general engineering skills to a specific engineering area.		
Note: Outcomes represent specific ABET accreditation criteria.		
Assessment Plan Outcome	**Describe potential for assessing the outcome using the provided project scope description**	**Rating: 1= min., 5 = max.**
c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.	This project will require students to develop engineering designs for LED lighting and related justification. This includes economic, physical, logistic, and environmental constraints.	4

d) an ability to function on multi-disciplinary teams	The project requires a team of students and a complex, multi faceted approach. In addition, the industrial client will be involved in the project	5
e) an ability to identify, formulate and solve engineering problems	Students will need to understand current lighting technology and the major technological shift in LED technology. This is real engineering problem for our local public utility.	4
f) an understanding of professional and ethical responsibility	Energy reduction and the importance of a critical and major change in technology which is occurring in the lighting industry. These two facets both illustrate the importance of professional development relative to technology changes and the importance of energy issues.	4
g) an ability to communicate effectively	Industry client will develop critical communication skills	4

Paul Kauffmann completed his B.S. in electrical engineering and MENG in mechanical engineering from Virginia Tech and a PhD in Industrial Engineering from the Pennsylvania State University at University Park. His background includes over 20 years of industrial experience with a Fortune Ten corporation where he held positions as plant manager and director of machine design engineering. He is a registered professional engineer in Virginia and North Carolina and teaching experience includes courses in graduate and undergraduate engineering and MBA programs. In addition he has taught executive development courses for organizations such as the Joint Forces Command, NASA, the US Navy, Canon, Siemens, and Northrop Grumman Ship Systems. Topics he has taught include logistics and supply chain management, statistics and quality control, risk analysis, production planning, operations analysis, engineering economics, and complex decision analysis. Research interests include statistical methods for data analysis, product development and quantitative methods in risk and operations analysis.

Gene Dixon is a faculty member at East Carolina where he teaches aspiring engineers at the undergraduate level. Previously he has held positions in industry with Union Carbide, Chicago Bridge & Iron, E.I. DuPont & de Nemours, Westinghouse Electric, CBS, Viacom and Washington Group. He has spoken to over 25,000 people as a corporate trainer, a teacher and a motivational speaker. He received a Ph.D. in Industrial and Systems Engineering and Engineering Management from The University of Alabama in Huntsville, a Masters of Business Administration from Nova Southeastern University and a Bachelor of Science in Materials Engineering from Auburn University. He has authored several articles on follower component of leadership and is active in research concerning energy, engineering education, and leadership processes.