A Framework for Developing a Deeper Understanding of the Factors that Influence Success and Failure in Undergraduate Engineering Capstone Design Experiences

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Abstract

The engineering undergraduate curriculum presents substantial opportunities for improvement. Society is calling for a transformation (https://tuee.asee.org/). As the culminating experience for undergraduate engineering students, capstone design team projects represent a window on the curriculum and a particularly fertile ground for understanding these opportunities. However, the factors that influence success and failure in capstone remains an area of inquiry. The framework presented here proposes to help us develop a deeper understanding of these factors.

We present a mixed methods analysis approach for identifying the critical factors impacting capstone design team success, where success is defined by student satisfaction. The proposed framework includes factors and their interactions in three fundamental areas: faculty mentorship, student backgrounds, and various contextual influences.

The proposed framework capitalizes on the use of existing survey tools and course data to conduct a mapping of faculty mentor beliefs/practices against student perception and recognition of those practices. In conjunction with student reflective memos containing self-evaluations of their project and team experiences, interactions with faculty mentors, and overall satisfaction with their educational experience, this data will combine to provide a multifaceted assessment of which factors are influential and are value-added to the program. The mixed methods approach will include quantitative statistical analysis of programmatic data, qualitative social network analysis-based assessment of peer evaluations, and case-study triangulation with student-authored reflective memorandum and faculty self-assessments.

Preliminary results from application of the proposed framework at a large public metropolitan research one university will be shared. The ultimate objective of this work is to provide a meaningful in-depth understanding of the capstone design experience and insights based upon careful analysis and observations of engineering students working on “real-world” projects. It is envisioned that the results of the research will provide meaningful guidance to students, instructors and stakeholders for improved preparation of young engineers for the profession.

Background and Outline

With EC2000, ABET brought a paradigm change to engineering education that has continued through to the present day [1]. Beyond providing a foundation of science, math and engineering fundamentals, engineering programs needed to do more. In addition to a new focus on student outcomes, ABET imposed a new course requirement; a culminating experience (a.k.a. capstone) to provide graduating students with awareness, knowledge and skills for solving the challenging real-world problems that they would face in their careers [2]. The challenge for engineering programs became an issue of how to fulfill this new requirement. How do we teach students to think and act like real engineers?

The introduction of the capstone course into the engineering curriculum signaled a return to a style of engineering education focusing on active experiential learning. At the time, relatively few resources were available for teaching modern engineering design in the broader context of global, cultural, social, environmental and economic factors [3, 4].

To help deal with the need for understanding the new experiential learning approaches in capstone and engineering education in general, research programs in engineering education were developed at various universities [5]. These new engineering education research programs served to expose deficiencies in our understanding of engineering design and teamwork in an academic setting, as well as the research methods used to develop that understanding [6] [7] [8] . While surfacing issues and challenges pertinent to the question of how to improve our teaching of students to become engineers, it is clear that further research is still needed to help us understand the inner workings of actual student teams in a natural setting [9]. What are the factors that make capstone students successful? Who are the observers in this natural setting that have the perspective and resources to make such a determination? Presumably, faculty who serve as capstone project advisors are the most likely candidates to have the appropriate perspective and may be the best observers. However, the very individuals who are immersed in the natural setting as capstone faculty advisors (a.k.a., project mentors or coaches) may not have the objective perspectives (nor appropriate time and inclination) necessary to conduct thoughtful unbiased assessments.

There is a need to improve our understanding of experiential teaching methods in the context of engineering capstone design. What are the factors that influence student success? How do faculty advisors impact teamwork? What are the requisite skills and backgrounds needed by faculty advisors to properly guide students to become engineers? How does the nature of a project, the preparation and background of a student, or the skill mix of a team affect the learning and development process? The complexity of the interplay between these factors makes extracting the assessment from the natural setting a challenging task.

In this paper, we will first provide a summary of some of the past efforts to improve our understanding of the potential factors that contribute to student success in capstone, along with the overarching objectives and approach for our work. Since defining student success tends to be somewhat subjective, we will then provide a brief commentary on the varying viewpoints and share a concise listing of the metrics in the proposed framework. An outline of the mixed methods framework will then be presented, complimented by descriptions of the survey instruments we have used to capture data from students and faculty. An overview of the case study analysis approach used to develop a deeper understanding of the factors that influence student success will then be presented, including summary data from nine case studies. Finally, this paper will share some of the preliminary observations from our initial implementation of the framework, concluding with a summary and plans for future work.

Review of Prior Work, Objectives and Approach

The ABET requirement to include capstone projects as a critical component of engineering education necessitated engineering programs to embrace active experiential learning. However, making fair and accurate student assessment in this kind of learning environment can be challenging, even for the best teachers. While past efforts to develop assessment methodologies for engineering capstone design have shed light on the subject [10, 11], it still remains unclear what truly makes one capstone team successful and others, perhaps less so. This very lack of clarity is a call for additional investigation into the relevant factors that influence student engagement and success. In the interest of seeking clarity on student project success, many researchers have focused on a variety of specific factors or methods that influence success.

For example, it seems logical to assume that team composition may have a significant impact on project success. The confounding issue here is that there are many approaches described in the literature on team selection and making project assignments [12] . At one extreme, there is random assignment, which is probably not advisable for technically challenging open-ended capstone projects where a diversity of engineering experience and skills may be required [7]. Other approaches include grouping students based upon similar grade point average [13], personality profiles [14], student self-selection, or weighted mathematical algorithms of various forms [15, 16]. However, Aller, Lyth and Mallak [17] note that shared interests and motivation are probably the best predictors of team performance and "much more so than the methods identified."

Of course, this implies that project definition and the very nature of the project itself may also be factors. Bracken, et. al. consider the attributes for successful capstone project selection [18]. They conclude that perceived value of the project to students, relevance to the engineering discipline and the use of emerging "cool" technologies are factors, with the caveat that once a project commences and regardless of the project selection, that "having a crisis management plan enables the capstone practitioner to respond to the crisis in a calm and rational manner." They go on to observe that "while a failed capstone project often leaves both the student, and sponsor (if applicable) and faculty project advisor disappointed, this doesn't mean that learning has not taken place." Clearly, challenge level may also be a factor associated with capstone project selection. In this vein, Pezeshki, Leachman and Beyerlein have explored the use of NASA Technology Readiness Levels along with resource and risk assessments to improve capstone project scoping in the interest of improving successful delivery of student project deliverables [19].

Another related factor may also include the initial perceptions students have when they are introduced to a capstone project. Hart and Polk examine these factors in the interest of offering appealing projects that "excite" and "engage" students [20]. Deriving results from their work it appears that the factors of importance to student capstone project preference can be summarized as follows:

Factors	Importance
Interest in Project Area or Technology	78%
Sponsor Reputation (Employment)	67%
Well Defined Project Scope	67%
Perceived Importance of Project	59%

In addition to the possible success predictors of assessment, team composition and project definition, there are a host of other, perhaps more narrowly defined characteristics that have been described in the literature that may have influence on capstone project success. This includes factors such as team diversity [21, 22], team size and project duration [20, 23, 24], the experience level of students [12, 25-27] and how student leadership emerges on capstone teams [28-30].

Clearly there are many studies that seek to address the apparent critical factors contributing to student success in a capstone experience, however it appears that we continue to lack insights into identification, detection and prioritization of the actual main factors and the associated interactions that may influence student success on capstone engineering design projects. Recent work by Pembridge & Paretti [9] indicates a substantial variation in the behaviors and teaching methods utilized by capstone instructors depending upon their own personal experience base. Significantly, they do not attempt to identify teaching best practices, acknowledging the highly complex and context dependent nature of capstone instruction. Notably, none of the primary teaching behaviors explored in their work focus on content-specific, so called “technical” knowledge; emphasizing instead the social, motivational, and developmental aspects of engineering education.

In the work presented here we attempt to offer insight into the real-time contextual issues of capstone design to make the connections between teaching practices, student engagement and contextual influences. Our efforts are clearly a work in progress and propose to take advantage of the natural-environment experiences of capstone participants, using a mixed methods approach to shed light on the complexities associated with the capstone teaching environment. In contrast to the analytical approach which is typical of engineering practice, it must be acknowledged that there is likely no single equation or algorithm to predict and model capstone success factors, and that the influences are more subtle, situational, and nuanced.

The proposed framework utilizes a sample subset of capstone project case studies (drawn from a large candidate pool), identified using survey instruments and course data to explore and identify teaching practices that are effective in eliciting successful capstone results. The framework assumes that each capstone project team represents a case study and for each student team a faculty advisor has been assigned to provide direct guidance and ultimately assign a grade to each student on the project team.

A Mixed Methods Framework for Understanding Student Success

In keeping with the teachings of John Dewey, we postulate that the influences from faculty, students, and the project context and environment are inseparable and overlap in capstone (Figure 1), and in fact have an “intimate and necessary relation” [31].

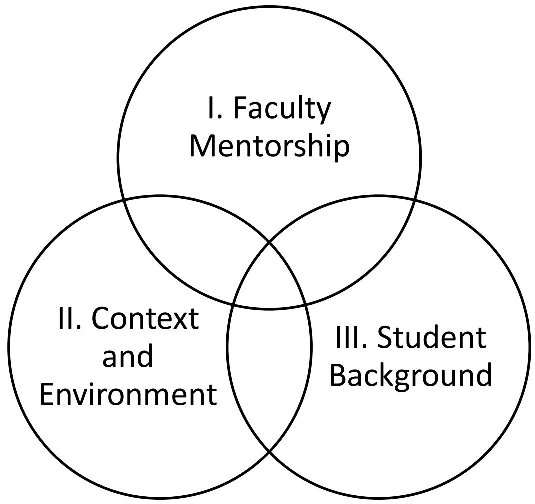

Figure 1- Capstone Faculty, Contextual and Student Factors

Given this setting, the proposed framework (Figure 2) for analysis involves a mixed methods approach including analysis of student and faculty survey data and existing programmatic data, along with case study analysis for triangulation involving student peer evaluations and end of semester reflective memos [32] . The following sections of the paper will describe in greater detail the various elements of the proposed framework.

Although capstone courses are common across ABET accredited programs, we must acknowledge that they vary significantly in their implementation [33]. From Howe's work a sampling of some of the differentiating characteristics are shown in Table 1 below.

Characteristics	Representative Examples
Duration	One to Two Semesters
Lecture Topics	design process, teamwork, project planning, engineering ethics, intellectual property, etc.
Sources of Projects	Academic, Student Proposed, Service, Industry, etc.
Assessment Methods	Project Reports, Design Reviews, Peer Evaluations, Effort Reports, etc.
Size of Student Population	10 to 200+
Average Team Size	3 to 9
% Department Faculty Receiving Teaching Credit	0 to 100%
Average Project Funding	$0 to $50K

Table 1 - Capstone Course Characteristics

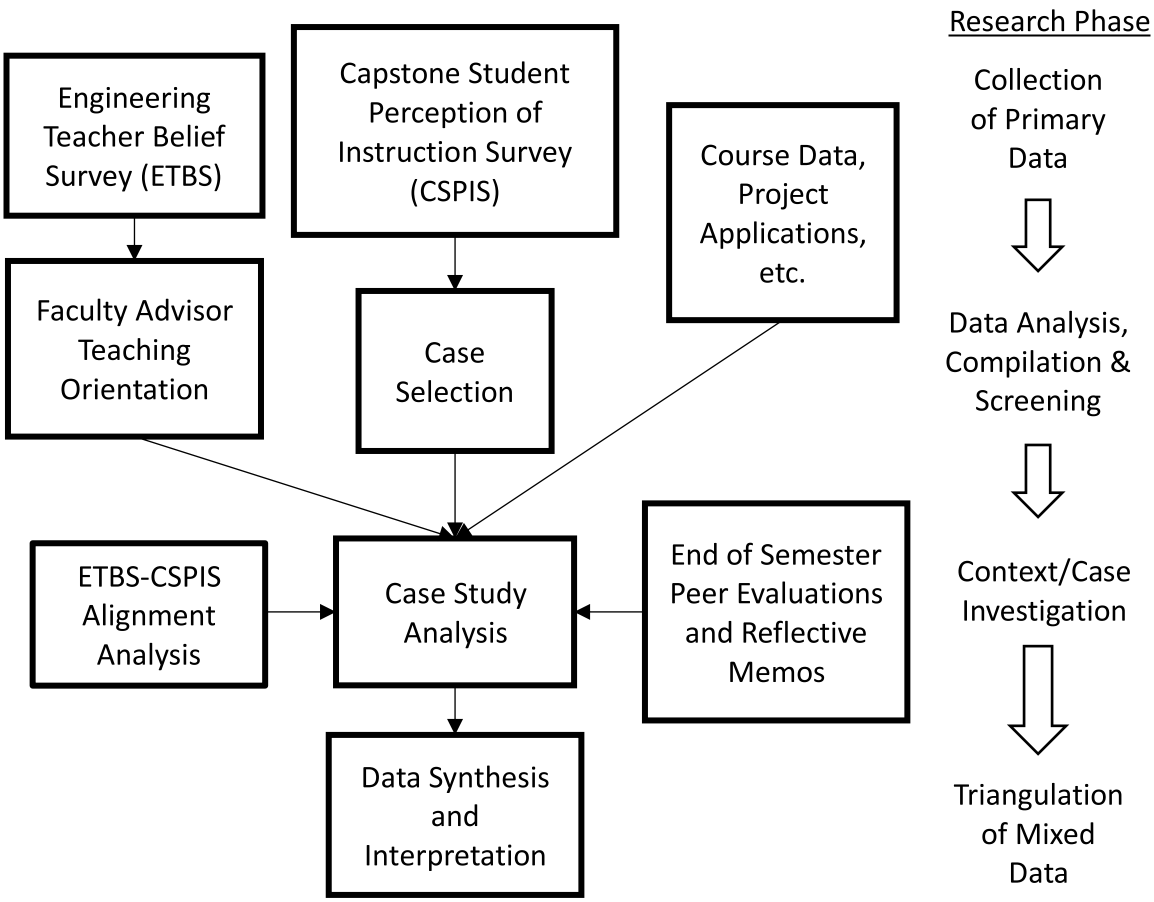

Figure 2 - Mixed Methods Research Framework

Regardless of the variations from one program to another the common denominators include; 1.) an engineering design project, 2.) a student team, and 3.) some level of faculty guidance.

For the work presented here the broad context is a large public metropolitan university. The student population is composed of mechanical and aerospace engineering. The curriculum structure is a two semester offering consisting of six major course milestones that emulates industry practice [34]. The lecture component of the capstone course is conducted by the course coordinator who provides instruction and general guidance on the engineering design process to all students. The course coordinator assigns students to projects based upon information provided by students about their project preference and background (i.e., resume). The course coordinator also assigns a faculty advisor to each project team, who mentors and provides direct guidance to the student team.

Defining Successful Student Outcomes in Capstone

The Engineering Accreditation Commission (EAC) for ABET describes student outcomes in terms of the skills and abilities that students possess or acquire through their education [35] . This paper builds upon past work, where we take the viewpoint that capstone is a proving ground for students to demonstrate that they are prepared for professional practice [2] . The outcomes of the capstone educational experience, therefore, can be broadly characterized to encompass all of the new EAC defined student outcomes 1 through 7.

Depending upon one's viewpoint there may be different definitions for success in capstone. For example, some faculty may value project results as a metric of student learning outcomes. Did the prototype demonstration work according to specification and was the final report well written? In contrast, other faculty may consider how well students collaborated on a team, followed the design process and learned from their failures as the best indicator of successful student outcomes. We argue that success in capstone includes both of these perspectives and more; including student, faculty and contextual/environmental considerations.

Of course, as shown by Gonzalez-Rogado, et. al., student success will be influenced by a multitude of factors, including (most notably) teaching practices [36]. Given the multitude of teaching practices that may impact student success, past efforts to quantitatively determine student engagement will depend upon the characteristics measured. Gonzalez and Rogado, et.al. noted that "students who are most satisfied are those who follow a course based on a teaching methodology that involves them more in the learning process…" This suggests that an investigation going beyond a numerical assessment of teaching practices should also include the "voice of the student" on what practices resonate with their individual needs. Identification of which practices correlate to student success will require triangulating quantitative assessments with qualitative observations capturing student feedback (i.e., a mixed methods assessment).

Below (Table 2) is a concise listing of the capstone student success outcome metrics included in the framework presented here. All of the types of information and data are regularly collected as an integral part of the course, except for the Capstone Student Perception of Instruction Survey (CSPIS).

1. Course Data (project milestone assessments)
2. Project applications and resumes used to assign students to project teams
3. Individual student contributions to the team project as judged by faculty advisors
4. Student peer evaluations as an indicator of teamwork and for comparison (or calibration) with faculty individual assessments of individual student contributions
5. Feedback from student reflective memos describing what they learned and how their motivation may have been affected throughout the project
6. Capstone Student Perception of Instruction Survey (CSPIS)

Table 2 - Student Success Outcome Metrics

Capstone Student Perception of Instruction Survey (CSPIS)

A common routine for most universities and colleges around the world is to administer student perception of instruction (SPI) surveys at the end of each semester at the course level to gauge teaching effectiveness. SPI survey questionnaires are typically the most influential measure of teaching effectiveness at most institutions and considered to be reliable and valid instruments [37]. For a course with multiple instructors (i.e., faculty advisors), results from course level SPI surveys lack the level of detail necessary to truly understand the impacts of teaching practices on individual project teams. Similar to the questions used by the traditional SPI questionnaire we developed questions that would provide insight into teaching effectiveness at the individual capstone project level based upon Pembridge and Paretti's functional taxonomy [38] . The questions, based upon a 5 point Likert scale, were customized for the contextual setting of capstone and organized into five areas:

1. Individual Student Interests
    a. My faculty advisor actively promotes my individual educational/engineering development.
    b. My faculty advisor adapts project guidance based upon individual student interests and capabilities.
2. Technical Guidance
    a. My faculty advisor is engaged in and aware of the technical aspects of my project.
    b. My faculty advisor helped guide the team in finding relevant technical information.
    c. My faculty advisor provided specific technical knowledge related to the project.
    d. My faculty advisor is more focused on the technical accomplishments of the project than my educational development
3. Teamwork
    a. My faculty advisor is invested in ensuring our team work environment promotes a healthy exchange of ideas.
    b. My faculty advisor helped maintain involvement and motivation for each individual student.
    c. My faculty advisor helped mediate or facilitate team interactions.
    d. My faculty advisor knows individual student contributions from team members.
4. Design Process
    a. My faculty advisor helped guide the development of project deliverables.
    b. My faculty advisor helped define/refine the project scope.
    c. My faculty advisor helped guide students through a structured design process.
5. Role Model
    a. My faculty advisor has one or more characteristics that are valuable to me as a professional role model

The CSPIS was implemented by the course coordinator on a voluntary basis to all students during the middle of the second semester of a 2-semester capstone course during the 2019 academic year. For each response, individual students were requested to include their name and project identification. With a population of 264 students organized into 48 capstone project teams, 183 completed surveys were collected from the possible respondents. Summary data from the population of students who responded to the CSPIS is shown in Table 3 below.
Of these, nine project teams were selected for further case study analysis. Project teams were selected to include a wide variation of characteristics based upon the source of the project (i.e., industry sponsored, faculty defined, student-proposed or research/university support) and the backgrounds of the faculty advisor (i.e., industry or academic). The projects chosen for further case study analysis also had a maximum number of students on a team who actually responded to the CSPIS survey.

	Individual Student Interests	Technical Guidance	Teamwork	Design Process	Role Model	Overall CSPI
Max	4.75	4.62	4.50	4.83	5.00	4.50
Median	3.56	3.59	3.47	3.67	3.92	3.59
Min	2.81	2.38	2.56	3.00	3.58	2.76

Table 3 - CSPIS Total Individual Student Population Data Summary (n = 183)
(ratings based upon 5 point Likert scale)

Engineering Teacher Belief Survey (ETBS)

In parallel with the implementation of the CSPIS, the Engineering Teacher Belief Survey (ETBS) was also administered to each of the faculty members who served as project advisors. The ETBS is based directly upon the Teacher Belief Interview (TBI) [39, 40]. The fundamental principle of the TBI is that instructor beliefs have direct relationships to teaching practices. For example, Moore et. al. use the TBI to track changes in teaching practices to investigate how model-eliciting activities can influence changes in beliefs over a three-year period [39]. The TBI probes for instructional beliefs in areas of student learning, assessment and teaching practice and manifests itself in seven specific questions as presented by Moore et. al. as follows:

1. How do you describe your role as the instructor? (Teaching practice)
2. How do your students best learn engineering? (Student learning)
3. How do you maximize student learning in your classroom? (Teaching practice)
4. How do you know when your students understand? (Assessment)
5. How do you decide what to teach or what not to teach? (Teaching practice)
6. How do you decide when to move on to a new topic in your class? (Assessment)
7. How do you know when learning is occurring in your classroom? (Student learning)

The TBI questions as originally presented by Luft and Roehrig [41] were further categorized into seven categories that reflect the views of faculty about students, as follows:

1. Traditional Teacher Focused (TTF)
2. Instructional Teacher Focused (ITF)
3. Transitional (T)
4. Responsive Student Focused (RSF)
5. Reform-based Student Focused (RBSF)

The seven questions and five categories serve as a foundation for the thirty-five questions implemented in the Teacher Belief Survey or TBS [42], which is grounded in many years of research and considered to be reliable and valid. For our purposes, we customized the wording of the thirty-five questions in the TBS to reflect the special teaching environment associated with engineering capstone to create the Engineering Teacher Belief Survey (or ETBS). As shown in Table 4 below, the Engineering Teacher Belief Survey (ETBS) questions were developed, targeting the interaction between faculty advisor beliefs and the behaviors they exhibit, closely following the outline provided by Luft and Roehrig [41] . In actual implementation, the sequence of questions is randomized and quantified on a five-point Likert scale. An example of the resulting radar charts for one of the nine faculty advisors in the case studies is shown in Figure 3 below.

TTF1	I view my role as an educator as a technical expert who delivers engineering knowledge content.
TTF2	My students learn engineering best by taking good notes and paying careful attention to me during design meetings.
TTF3	Careful planning by the faculty advisor and well prepared agendas maximize student learning.
TTF4	Students develop an understanding of the content based upon information delivered to them in design sessions.
TTF5	The syllabus provides guidance on what to teach students for their specific design project.
TTF6	I encourage students to move on to new phases of their design project after they have expended the time allotted by the course schedule.
TTF7	When students are paying close attention to me during design sessions I know that learning is occurring.
ITF1	As an engineering educator, my job is to motivate student interest to learn technical content.
ITF2	My students best learn engineering by integrating technical content from prior coursework into their projects.
ITF3	As an engineering educator, I maximize learning and comprehension by carefully observing student responses during design sessions.
ITF4	I know students understand when they are correctly applying technical solutions to their project.
ITF5	I know what guidance or instruction to provide based on what students need for their professional practice.
ITF6	I encourage students to move on to the next phase of the design process when they understand the design principles for the current phase.
ITF7	I know that learning is occurring based on critical assessment of design deliverables (reports, presentations, etc.)
T1	My role as an educator is to serve as a guide for developing understanding of engineering principles and practice.
T2	Students best learn engineering with hands-on laboratory/prototyping activities.
T3	To maximize student learning I build a positive supportive environment.
T4	I know students understand when they can describe what they have learned.
T5	I decide what to teach or what not to teach based upon student feedback.
T6	I move on to a new topic in when students are able to use the design process to solve problems.
T7	I know when learning is occurring when the students are actively engaged.
RSF1	My role as an engineering educator is as a facilitator who sets up the project for students to engage in inquiry and exploration.
RSF2	Students best learn engineering when they interact with each other as they explain their results.
RSF3	To maximize project-based learning I use design sessions to encourage students to share ideas, predict results and ask questions.
RSF4	I know students understand when they can use the knowledge gained to solve a practical problem
RSF5	I manipulate project scoping based upon the interests and capability of students.
RSF6	I encourage students to move forward onto new project phases when students are comfortable with the content.

RSF7	I know learning is occurring for the project team when the students interact and work together to solve problems.
RBSF1	My role as an engineering educator is as an advisor and mentor who helps students reconcile what they know and what they can learn.
RBSF2	Students best learn engineering when they take ownership of what they have learned.
RBSF3	I maximize student learning by allowing students to choose their own methods for learning.
RBSF4	I know students understand when they can apply fundamental engineering concepts to expand their knowledge in new areas.
RBSF5	I decide what to encourage students to develop for their projects based upon what is cognitively appropriate for students and aligned with accepted standards.
RBSF6	I encourage students to move on to new topics when they are applying the concepts to new situations and asking questions about the concepts.
RBSF7	I know when learning is occurring when students formulate thoughtful questions about the project.

Table 4 - Engineering Teacher Belief Survey (ETBS) Questions

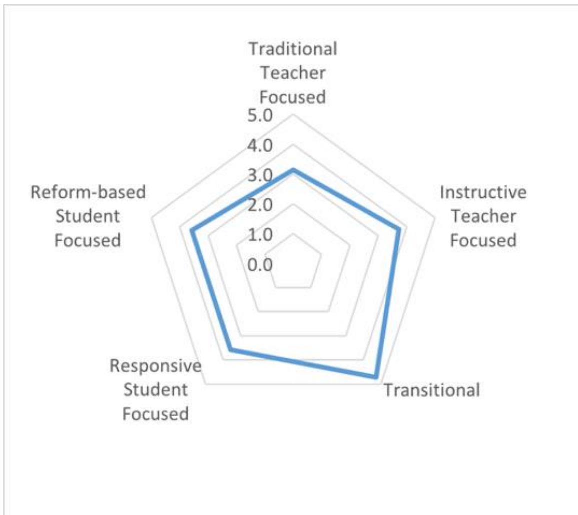

Figure 3 – Example Faculty Advisor ETBS Radar Chart

Case Study Analysis

The deeper insights into the character and complexion of the dynamic engineering capstone educational environment are well-suited for the utilization of case study investigations, having used the screening process to extract characteristics of representative teams and faculty from the field of candidates. The selection process allowed investigation of faculty mentoring methods from various classes of faculty (i.e., tenured, research, lecturer and industry adjunct). Open ended interviews with faculty advisors for the selected cases also provided insights into the more nuanced social interactions between team members and faculty advisors.

A recurring theme in case study research methods is the premise of triangulation, suggesting that multiple supporting sources of evidence or "convergence of the evidence" [43] is desirable.

Researchers are encouraged to gather multiple types of data, using independent processes, to ensure that their conclusions are well-grounded. Yin (2009) suggests various types of data may include written documentation, open-ended interviews, observational studies, structured interviews, as well as quantitative methods (e.g., surveys). Such multi-vector support for factual observation lends credence to the validity of the observations and is consistent with generally-accepted mixed-methods research methodology.

As described in the previous two sections of this paper, student perceptions of instruction were gathered via survey (i.e., the CSPIS) to provide a complimentary perspective to the faculty advisor ETBS results. As a basis for the case study analysis, we utilized Pembridge's and Paretti's taxonomy of capstone teaching characteristics which served as a guide and useful starting point for assessing faculty roles and student perception [9]. Their taxonomy probes such characteristics as:

- Enabling students on real world projects, structured design processes, prototyping and interdisciplinary teamwork
- Importance of student learning outcomes in areas of writing, goal setting, team communication, teamwork and creative thinking
- Faculty advisor/instructor roles in areas of scoping projects, guiding and helping teams organize/plan, and maintain student involvement/motivation
- Characteristics of "a good capstone instructor", such as passion for teaching design or in the project area, knowledge of design processes, managing and facilitating the team, knowing students' individual characteristics/habits/personalities, and prior industry or applied engineering experience

While the ETBS speaks to a faculty member's beliefs, the CSPIS provides insight into the student perspective of how faculty advisor beliefs manifest in the faculty member's teaching methods. The pairing of the ETBS coupled with the CSPIS provides insight into how faculty beliefs translate into practice. For each of the nine case studies, an analysis was conducted to evaluate how faculty advisor teaching practices aligned with student perceptions of instruction for the particular capstone project under consideration.

Secondary data from internal course assignments and metrics (i.e., end-of semester reflective memos, peer evaluations, project applications, student resumes, grades, etc.) complemented the survey data to provide a first-tier (screening) assessment of significant parameters. End of semester reflective memos and peer evaluations were particularly revealing with regard to students' perceptions of their learning experience and their relationships with teammates. Project applications and resumes were used to develop a composite understanding of the experience level of the various students on project teams for each of the case studies.

For each case study, we conducted an in-depth multi-vector analysis, including triangulation to provide a definitive assessment of faculty advisor mentorship (type I factor); context and environment (type II factor); and student influences (type III factor); for each of the nine capstone projects, culminating in an overall assessment of capstone project success. Table 5 below provides summary data from each of the case studies. The case studies are coded with prefixes indicating the source of the project as follows:

FD ➔ Faculty Defined Project
ISP ➔ Industry Sponsored Project
RUS ➔ Research/University Support
SPP ➔ Student Proposed Project

The summary data in Table 5 uses direct CSPIS team average ratings for type I faculty advisor mentorship. The remaining summary data uses a four-point scale to quantify the type II and III factors, and the overall assessment of project success based upon case study analysis as follows:

4.0 ➔ excellent
3.0 ➔ good
2.0 ➔ satisfactory
1.0 ➔ poor

Case Study	**Faculty Advisor Mentorship (Type I)**	**Context & Environment (Type II)**	**Student Influences (Type III)**	**Overall Assessment of Project Success**
FDP2	2.9	3	3	**3**
ISP3	2.2	1.5	2	**2**
ISP2	3.6	3	4	**4**
ISP1	3.2	3	3	**3**
RUS2	3.5	2	3	**3**
SPP1	2.9	3	4	**3**
FDP1	2.8	3	2	**3**
RUS1	2.6	3.5	1	**2**
SPP2	2.8	3	2	**4**

Table 5. Case Study Summary Data

Preliminary Observations

Preliminary observations from the case study analyses revealed that faculty engagement, clarity in project definition, and strong team dynamics, in combination, resulted in greater overall project success. We found that contextual (type II factors) and student influences (type III factors) were predominantly manifested in issues related to project definition and team dynamics, respectively. Improving clarity in project definition appears to result in slightly better overall project success, as compared to improvements in faculty engagement and team dynamics.

It appears that clarity in project definition may have positive impacts on team dynamics. Issues with team dynamics resulted in higher variability in overall project success, whereas improvements in faculty engagement and team dynamics resulted in greater consistency of overall project success.

We observed that lack of clarity in initial project definition can have a particularly deleterious impact on student success. For the case studies examined we found two project teams (RUS1 and ISP3) with serious issues requiring protracted intervention. In the case of RUS1, the team experienced issues with project definition during the first semester and "institutional" support issues during the second semester. Despite these issues the team had a faculty advisor who was sensitive to student issues and provided the necessary support to facilitate the team's progress. In the case of ISP3, the industry sponsor was not as initially responsive as would have been beneficial to the students. Consequently, the student effort lacked focus and direction for an extended period of time at project kickoff. The faculty advisor was not able to coordinate with the sponsor due to some of the very same issues that the student team experienced. Although the faculty advisor (an industry adjunct) had a demonstrated ability to successfully guide project teams, the faculty advisor had schedule and time constraints due to other commitments that hampered the level of faculty engagement.

For seven of the nine case studies, we found a strong positive correlation of 83% between team design specification document grades (week 4 of the first semester) and team average CSPIS rating (data collected in week 8 of the second semester), suggesting that teams with a clear and early understanding of project requirements were more satisfied and engaged. Conversely, students on projects with unclear definition were less satisfied. Comments from end of semester student reflective memos provided insight into the impact of project definition issues. For those projects with issues, student comments focused on uncertainty and changes in project direction; and how these issues resulted in a negative impact on their motivation and engagement. Intervention consisted of facilitating communication with the student teams and helping them understand, clarify and come to consensus on project objectives. While the issue of unclear project definition is inherently contextual, we argue that ensuring appropriate project scope and clarity in project definition is a faculty and program/department responsibility and have identified the potential interaction as type I/II (see appendix).

We have noticed from the case study analysis that for research university support (RUS) and industry sponsored (ISP) projects, unclear project definition can often be very challenging for students, as compared to a faculty defined project where goals and objectives have the opportunity to be very well defined. Adding to the issue, project definition can sometimes change as the student team consults with their industry sponsor or research/university liaisons. While industry and research project liaisons will typically be comfortable with such fluidity, we find that students, particularly those lacking engineering experience, such as internships or significant projects (e.g., SAE formula car) will express significant consternation and frustration with changes in project definition. The case studies indicate that faculty with industry experience, who tend to be well versed in the engineering design process are generally astute to these particular issues and aware of the appropriate interventions for remediation. In contrast, we found that faculty-defined projects with well-defined goals and objectives in the area of the faculty member's expertise can have equally satisfying results for capstone student projects.

Another recurring issue which surfaced as a result of our case studies, focuses on the issue of team dynamics and student leadership (or lack thereof). As others have found [29], the failure of student leadership to emerge on capstone project teams can have a significant impact on team dynamics leading to less than satisfying results and success in a capstone experience. We know from prior work [12] that students with engineering work experiences (i.e., internships, cooperative education experiences, etc.) will often emerge to serve in the role of project team leaders. Our general practice is to create diverse teams based upon information students provide via a project application form. The information includes project preference, technical skills and prior engineering work experience. Nevertheless, whether a capstone team has been formed with students that have prior engineering work experience, does not necessarily guarantee that student leadership on a team will emerge. This requires faculty advisors to facilitate teamwork and encourage student leadership. From our case studies, we have observed that faculty advisors with a more traditional teacher focus may or may not have sufficient inclinations to identify dysfunctional student dynamics (which inevitably comes from lack of student leadership) until it becomes too late to intervene and remediate issues. Faculty with prior industry or management experience may develop these skills due to their industry experiences. In contrast, faculty without industry experience who are more student-focused also tend to exhibit more insight into team dynamics. Confirming Novoselich's and Knight's findings [30], our case studies suggest that teams with shared leadership have more successful student outcomes and a more satisfying learning experience.

Summary

We have presented a mixed methods framework for developing a comprehensive in-depth understanding of the issues and success factors associated with capstone design teams. Two new survey instruments specifically customized to cater to the capstone community (i.e., CSPIS and ETBS) have been developed and implemented to explore the perspectives of both students and faculty. Using end of semester student reflective memos and peer evaluations, coupled with course and survey data, we have investigated individual project case studies to probe for a deeper understanding of some of the most significant issues that impact capstone student success. Early indications are that project definition, team dynamics and faculty advisor mentorship are key factors.

Future Work

Our study of the factors influencing capstone student team success remains a work in progress. Meanwhile, in the interest of exploring "positive" success factors, we have also taken into consideration the many potential "negative" impacts on team success, utilizing the perspective that we often learn more from our failures than from our successes. In the appendix to this paper we present a compilation of issues often expressed by students categorized in areas of faculty mentorship, contextual/environmental and student/team issues. They are presented in no specific order and are most likely not exhaustive, so the compilation is presented as observations from the field of inquiry based upon our case studies, as well as many years of working with capstone student teams. In addition to delineating the many possible issues that impact capstone student success, we have also noted some of the potential interactions of issues between the various areas (i.e., faculty, contextual, student).

As with the case study main factors, the issues are categorized into three primary categories (see appendix). Type I factors are faculty-derived, type II are contextual, and type III are student-centered. Examples of interactions might include:

- Faculty member not mediating project scope or allowing scope creep (Type I/II: interaction between faculty and context)
- Course/university schedule or logistical constraints that impede student progress (Type I/II: faculty creating project context)
- Unprofessional behavior of a team member (Type II/III: interaction between student behavior and team/project context)

We believe that exploration of these interactions and others, perhaps not yet identified (see appendix), is an area for future investigation.
Finally, we have started to gain insights into the teaching practices that have the opportunity to improve successful student outcomes. Many of these teaching practices appear to be consistent with the various focused efforts to validate specific teaching tools and methods described earlier in this paper. At this stage, however, our investigations and insights have only surfaced a set of questions to be used during semi-structured interviews with individual faculty advisors (which has yet to be completed). Here is our preliminary list of questions for faculty advisors:

1. How do you know if and when projects are scoped at an appropriate challenge level for students?
2. How do you know if students fully understand project objectives?
3. What do you do to encourage teamwork?
4. How do you know if and when there are team issues?
5. How do you know if the student proposed system concept will satisfy design requirements?
6. How do you integrate prior learning into your projects?
7. How do you know when students are actively engaged or not in the project?
8. How do you provide technical guidance that encourages students to think for themselves and sets the team up for success?
9. What do you do to encourage student leadership?
10. How do you encourage students to think like “real” engineers?
11. How does your teaching approach benefit students?
12. What do you consider the most important capstone student learning outcomes?

The framework presented in this paper provides a foundation for future work to develop a deeper understanding of engineering capstone design teams. Our immediate short term objectives are to complete the analysis phase utilizing the new framework. Longer-term efforts will likely focus on making the CSPIS a regular element of our capstone course in the interest of continuous process improvement. To further confirm our preliminary findings, we will conduct additional case studies in hopes of bringing focus and improved understanding to inform capstone teaching practices.

Acknowledgement

We are very grateful to the Guidish family for their unwavering support that has enabled us to pursue this research.

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Appendix - Issues Impacting Capstone Project Success

I. Faculty Mentorship Issues	Potential Interactions	II. Contextual Issues	Potential Interactions	III. Student/Team Issues	Potential Interactions
Failure of faculty advisor to mediate project scope	I/II	Insufficient space to develop and test prototype(s)	II	Unprofessional behavior of student (i.e., rude and inconsiderate)	II/III
Faculty advisor inaccessible to students	I/III	Forcing design process into academic calendar	II	Poor team management and planning	I/III
Faculty advisor does not follow course milestones/syllabus	I/II	Insufficient funds to procure components to develop and test prototype(s)	II	Student(s) unprepared for capstone experience (e.g.s., low GPA, lack of maturity,etc.)	II/III
Failure of faculty advisor to facilitate teamwork	I/II	Lack of manufacturing capability and/or know how to develop and test prototype(s)	II	from project (i.e., employment, family, extra-curricular, substance abuse, etc.)	II/III
Faculty advisor disengaged and/or does not care about project (failing to motivate students)	I/III	Insufficient computer and/or software availability and/or skills to accomplish project objectives	II	Unsatisfactory student participation (i.e., slackers who miss meetings, show up late, deliver poor quality/late work, do not communicate effectively, etc.)	II/III
Faculty advisor unaware and/or unappreciative of individual student work (i.e., roles, responsibilities, effort)	I/III	Purchasing issues (e.g.s., late delivery, ordering errors, not in stock, etc.)	II		
Faculty advisor is excessively demanding and/or challenging	I/III	Schedule and logistical constraints that impede student progress and teamwork	I/II		
Faculty advisor is mean and abusive (e.g., provides harsh feedback) to students.	I/III	Poorly scoped project at kick-off leaving team with unclear goals and lack of direction	I/II		
Faculty advisor provides little or no guidance or feedback to students	I/III	Scope creep that increases complexity and introduces excessive risk to project success	I/II		
		Faculty advisor staffing (e.g.s., inexperienced, not hired in time, background not aligned with project area)	I/II		
		Insufficient skill-base and/or multidisciplinary make-up of student team	I/II/III		