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A Mixed Method Analysis of Factors Influencing Success and Failure in Undergraduate Engineering Capstone Design Experiences

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A MIXED METHODS ANALYSIS OF FACTORS INFLUENCING SUCCESS AND FAILURE IN UNDERGRADUATE ENGINEERING CAPSTONE DESIGN EXPERIENCES

by

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ABSTRACT

The engineering undergraduate curriculum presents substantial opportunities for improvement [1, 2] . Society is calling for a transformation [3]. 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 work presented here proposes to help us develop a deeper understanding of these factors.

The research presented here uses a mixed methods analysis approach for identifying the critical factors impacting capstone design team success, where success is defined from both student and faculty perspectives. The framework for the research includes factors and their interactions in three fundamental areas: faculty mentorship, student backgrounds, and various contextual influences.

The research capitalizes on the use of survey tools and course data to conduct a mapping of faculty mentor beliefs and 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, the data will combine to provide a multifaceted assessment of which factors are influential and are value-added to capstone courses. The mixed methods approach will include statistical analysis of programmatic data, student perception of instruction surveys, social network analysis of peer evaluations, faculty teacher belief self-assessments and case-study triangulation with student-authored reflective memoranda.

The ultimate objective of this work is to provide an 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.

ACKNOWLEDGMENTS

It is my firm belief that no effort of this magnitude is ever completed without the influence and support of a myriad of individuals. This work would not have been accomplished without the support and encouragement of Dr. Mark Steiner, who invested countless hours in providing guidance, inspiration, and feedback. I would also like to thank Sue for having the patience to grant him the freedom to spend those hours. I would like to acknowledge the Mechanical and Aerospace Engineering Department Chair, Dr. Yoav Peles, for his recognition of (and advocacy for) engineering education as a significant research area.

There are various individuals who have provided inspiration and moral support, and I would be remiss if I did not include them. To Dr. Christine R. Stresau, thank you for setting the bar. To Katie, Kaitlyn, Kevin, and Kyle, thank you for your patience and understanding. This has been a long road, and I know I have not walked it alone.

In memoriam, I would like to acknowledge Dr. David Nicholson and Dr. Suhada Jayasuriya, mentors and past Chairs of the MAE Department. They both left us too soon, and their dedication to education will not be forgotten. It would be my hope that their families find solace that the torch has been taken up and their work will be carried on by another generation of educators.

For Christa, Gregory, Judith, Dick, Ronald, Mike, Ellison, Rick, Ilan, William, Kalpana, Michael, Laurel, and David, as a reminder that integrity in engineering can never, ever be compromised.

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LIST OF ACRONYMS

ABET	Accreditation Board for Engineering and Technology
CFD	Computational Fluid Dynamics
CSPI(S)	Capstone Student Perception of Instruction (Survey)
EAC	Engineering Accreditation Commission
EMF	Engineering Maturity Factor
ETBS	Engineering Teacher Belief Survey
FDP	Faculty Defined Project
FEA	Finite Element Analysis
IS	Industry Support [Project]
ITF	Instructional Teacher Focused
RBSF	Reform-Based Student Focused
RSF	Responsive Student Focused
RUS	Research/University Support
SP	Student [Defined] Project
SPI	Student Perception of Instruction
T	Transitional
TBI	Teacher Belief Inventory
TTF	Traditional Teacher Focused

CHAPTER I: INTRODUCTION

Background and Outline

With EC2000, ABET brought a paradigm change to engineering education that has continued through to the present day [4]. 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 [5]. 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 [6, 7].
As a result, the past couple of decades have seen increased research in the area of active experiential learning [8]. 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[9]. 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 [10] [11] [12] . 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 [13, 14]. 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 course coordinators and instructors 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 project mentors, coaches and faculty advisors 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 thesis a summary of some of the past efforts to improve our understanding of the potential factors that contribute to student success in capstone will first be presented, along with the overarching objectives and approach for this work. Since defining student success tends to be somewhat subjective, a brief commentary on the varying viewpoints will be presented, followed by a concise listing of the metrics used in this thesis to define student success. An outline of the mixed methods framework used to conduct the research will then be presented, complimented by descriptions of the survey instruments developed and used to capture data from students and faculty. The data will combine to conduct in-depth analysis on nine case studies. Based upon the case study analysis, a summary of the key factors and their interactions that influence student success will be presented along with theoretical foundations of the functional relationships. Finally, the unique contributions offered by this thesis will be highlighted along with practical implications, conclusions and recommendations for future work.

Review of Prior Work

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 instructors. While past efforts to develop assessment methodologies for engineering capstone design have shed light on the subject [15, 16], it still remains unclear what truly makes one capstone team successful and others, perhaps less so. Academic assessment in isolation of other factors is simply not always a good predictor of capstone success. This very lack of clarity is a call for additional investigation into the relevant factors which 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 [17]. 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 [11]. Other approaches include grouping students based upon similar grade point average [18], personality profiles [19], student self-selection, or weighted mathematical algorithms of various forms [20, 21]. However, Aller, Lyth and Mallak [22] 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 [23]. 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, 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 [24].

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 [25]. 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 [26, 27], team size and project duration [25, 28, 29], the experience level of students [17, 30-32] and how student leadership emerges on capstone teams [33-35].

It appears that much of the past research has often focused on the effects of various course interventions and parameters, while providing relatively little insight into identification of the main factors and their interactions that influence student success in capstone engineering design projects. Few efforts seek to offer insight into the real-time contextual issues of capstone design to make the connections between teaching practices and student engagement and satisfaction.

Three important questions still remain: What does success truly mean in the context of capstone education? What are the teaching practices in capstone design environments that can help our students be more successful? What are the appropriate programmatic, departmental, and institutional support structures that enable student success? Recent work by Pembridge & Paretti [13, 36] indicate a substantial variation in the behaviors and teaching methods utilized by capstone instructors depending upon their own personal experience base. Significantly, none of the primary teaching behaviors noted focus on content-specific, so called “technical” knowledge; emphasizing instead the social, motivational, and developmental aspects of engineering education.

Objectives and Approach

The work presented here in this thesis proposes to take advantage of the natural-environment experiences of capstone participants, using a mixed methods approach to answering those simple (yet profound) questions. 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 appear to be more subtle, situational, and nuanced. The proposed mixed methods framework for conducting the investigation will utilize 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 research 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.

Without attempting to formulate an explicit formulation for success, a hypothesis can be stated. That is, it is possible to define a set of teaching best practices and educational program management best practices that have an influence on student engagement and success in capstone. Theoretically, a set of functional (not explicit) relationships can be proposed to elaborate on the nature of the influences. In a disciplined engineering fashion, each factor can be examined to postulate the potential influence on capstone teams based upon the metrics that already exist within the program structure or can be synthesized from team performance. Clearly there are many factors that can make a difference in the success or failure of a capstone project. The objective of this work is to investigate the many factors and identify the most important ones.

CHAPTER II. DEFINING SUCCESSFUL STUDENT OUTCOMES IN CAPSTONE

Capstone Administrative Structure

Although capstone courses are common across ABET accredited programs, they vary significantly in their implementation [37]. From Howe's work a sampling of some of the differentiating characteristics are shown in the table below.

Table 1. Capstone Course Characteristics

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

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 case studies in this thesis, the broad context is a large public metropolitan university. The student population is composed of mechanical and aerospace engineering students. The curriculum structure is a two semester offering consisting of six major course milestones that emulates industry design practice. The lecture component of the capstone course provides instruction and general guidance on the engineering design process to all project teams. The first semester consists of the milestones 1 through 3, while the second semester consists of milestones 4 through 6. The following is a brief description of each course milestone:

Semester One

Milestone 1 - Team Formation

During this phase team members explore past work that may be relevant to the project, develop a shared understanding of project objectives, and start to define the roles and responsibilities for everyone who is participating on the project.

Milestone 2 – Requirements Definition

A phase in product and process development where the engineering team develops and documents a detailed understanding of the design problem. The process involves interpretation of customer requirements and their translation into engineering design parameters. A process of competitor benchmarking is used to ensure that design changes result in design improvements. Analytical models and engineering calculations are used to predict performance and provide guidance for design decisions. Requirements definition culminates in an engineering specification.

Milestone 3 – Concept Design

Concept design is a phase where solutions are developed in response to the engineering specification. Concept design involves two major steps. The first one is concept generation, which involves exploration of the many possible solutions to the design problem. The second step is concept selection, which involves a comprehensive and rigorous assessment of the possible concept solutions identified. In parallel with these two steps, students integrate visualization of the possible concept solutions, which may include use of simple sketches, schematics, geometric models (CAD) and 3D printing. During this phase of design development, students also utilize analytical modeling and simulation to evaluate conceptual design feasibility.

Semester Two

Milestone 4 - Statement of Work

The team prepares a brief project background statement that identifies relevant stakeholders and describes the benefits that they will receive if the project is successful. The statement of work includes the following four sections:

1) Long Term Objectives and Payoff (for Stakeholders)

2) Semester Objectives (with specific measurable parameters)

3) Technical Approach (including any special resource requirements and/or issues)

4) Project Plan with Deliverables and Dates

Milestone 5 – Critical Design Evaluation:

By this phase in engineering design development teams should have a comprehensive understanding of project objectives with a plan to achieve them. Each individual on the team is expected to have clearly defined roles and responsibilities that allow the team to execute tasks in a concerted and deliberate fashion. Meanwhile, as the team moves forward, there is a recognition that as elements of the project start to come together, there is also the potential for issues to arise. To mitigate risk and deliver on promises, successful teams continuously look to identify risk using various forms of risk assessment (e.g., FMEA). In addition, engineers put their analytical skills to work to create fine-tuned math-based models and conduct calculations to estimate and predict system performance. As the first prototypes come together, various tests (at the system, sub-system and component levels) are used to validate expected performance of critical design parameters. All the while, as critical design evaluation proceeds forward, the team continues to keep track of schedule and make changes as necessary.

Milestone 6 – Design Implementation

Design implementation occurs throughout most of the second semester and overlaps with Milestone 5. During this phase components parts are ordered, fabricated and assembled. The initial design realization is manifested in a design prototype for test, evaluation and demonstration. Design implementation culminates in a significant project demonstration, final design review with stakeholders and a comprehensive documentation of the design.

Student Success Outcome Metrics

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 [38] . This thesis takes the viewpoint that capstone is a proving ground for students to demonstrate that they are prepared for professional practice [5] . 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 (e.g., 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. This thesis argues 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 [39]. Given the multitude of teaching practices that may impact student success, past efforts to quantitatively determine student engagement will depend upon the characteristics measured. There is a temptation to assess many parameters simultaneously, however, this may lead to a lack of causal clarity. Gonzalez and Rogado, et.al. note 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”, further stating that the factors “vary depending on the didactic methodology employed in the teaching/learning process.” In a similar vein, Joo, Lim and Lee [40] explore the factors in capstone engineering design courses that effect student outcomes and conclude that instructors and course designers need to consider student satisfaction as a “critical indicator in evaluating capstone design courses.” Additional insights, pertinent to this thesis are that students indicated “higher perceived achievement when they had higher levels of teamwork competency” and that students with “goal-setting, coordination, communication, and leadership skills tended to perform better in project-based capstone design courses.”

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. For example, Steiner, et. al. uses end of semester reflective memos to develop a deeper understanding of student capstone learning based upon how they responded to the simple question; “What do you think you learned?” [41]. However, identification of which practices correlate to student success require triangulating quantitative assessments with qualitative instruments capturing student feedback (i.e., a mixed methods assessment).

For the purposes of this thesis, Table 2 presents a concise listing of the capstone student success outcome metrics included in the framework presented. All of the types of information and data are collected as an integral part of the course, except for the Capstone Student Perception of Instruction Survey (CSPIS). At most institutions, student perception of instruction (SPI) surveys are collected at the end of each semester at the course level by the registrar. For a course with multiple instructors (i.e., faculty advisors, coaches, mentors), results from course level SPI surveys lack the level of detail necessary to truly understand the impacts of teaching practices on individual project teams.

Table 2. Student Success Outcome Metrics

Metrics
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)

Identification of Issues Impacting Student Success

In the interest of exploring "positive" success factors, this thesis attempts to take 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. Table 3 presents 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 the case studies that follow, as well as many years of working with capstone student teams. In addition to delineating the many possible issues that impact capstone student success, the potential interactions of issues between the various areas (i.e., faculty, contextual, student) are noted.

These issues are categorized into three primary categories (reference Figure 1; Table 3). Type I factors are faculty-derived, Type II are contextual, and Type III are student-centered. A sample 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)

Table 3. 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	External influences that distract student attention away 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		

CHAPTER III. A MIXED METHODS FRAMEWORK FOR UNDERSTANDING STUDENT CAPSTONE SUCCESS

Overview of Methodology

In keeping with the teachings of John Dewey, it is postulated 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" [42]. That is, the interactions between the categories (i.e., faculty mentorship, student influences and context/environment) can be meaningful. Prior research generally bridges only two categories [8, 43].

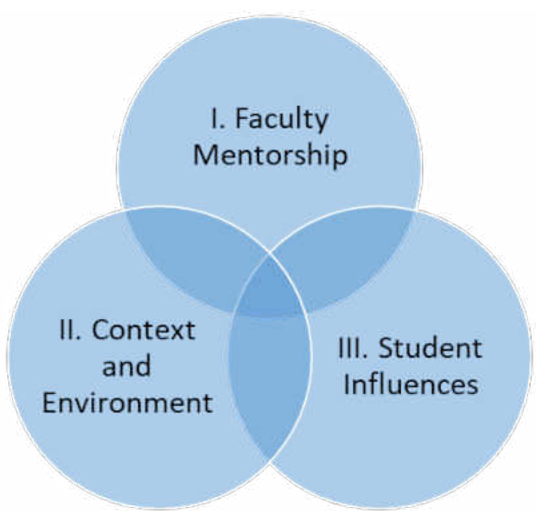

Figure 1 - Capstone Student, Faculty, and Contextual Factors

Given this setting, the proposed framework (Figure 2) for analysis involves a mixed methods approach including statistical analysis of student and faculty survey data and existing programmatic course data, along with case study analysis for triangulation involving student peer evaluations and end of semester reflective memos [44] .

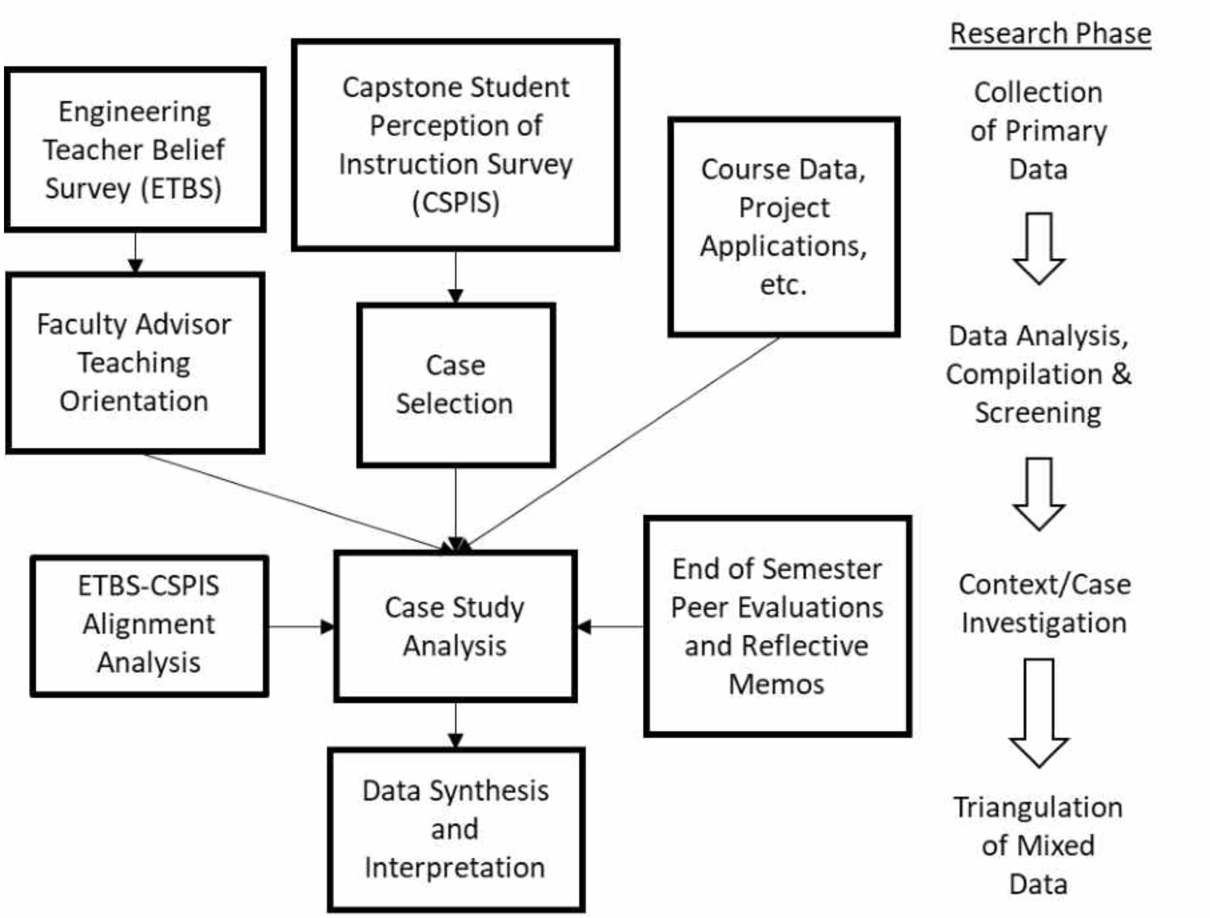

Figure 2: Mixed Methods Research Framework

Capstone Student Perception of Instruction Survey

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 are considered to be reliable and valid instruments [45]. 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 the Capstone Student Perception of Instruction Survey (CSPIS) was developed with questions to provide insight into teaching effectiveness at the individual capstone project level based upon Pembridge and Paretti's functional taxonomy [13]. The questions, based upon a 5 point Likert scale, were customized for the contextual setting of capstone and organized into five areas as follows:

Individual Student Interests

- My faculty advisor actively promotes my individual educational/engineering development.
- My faculty advisor adapts project guidance based upon individual student interests and capabilities.

Technical Guidance

- My faculty advisor is engaged in and aware of the technical aspects of my project.
- My faculty advisor helped guide the team in finding relevant technical information.
- My faculty advisor provided specific technical knowledge related to the project.
- My faculty advisor is more focused on the technical accomplishments of the project than my educational development

Teamwork

- My faculty advisor is invested in ensuring our team work environment promotes a healthy exchange of ideas.
- My faculty advisor helped maintain involvement and motivation for each individual student.
- My faculty advisor helped mediate or facilitate team interactions.
- My faculty advisor knows individual student contributions from team members.

Design Process

- My faculty advisor helped guide the development of project deliverables.
- My faculty advisor helped define/refine the project scope.
- My faculty advisor helped guide students through a structured design process.

Role Model

- 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 4 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.

Table 4: CSPIS Total Individual Student Population Data Summary

	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

Data sample (n=183); 5 point Likert scale

Engineering Teacher Belief Survey

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) [46, 47]. 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 [48]. 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 [49] 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 [50], which is grounded in many years of research and considered to be reliable and valid. For the purposes of this work, the wording of the thirty-five questions in the TBS was customized to reflect the special teaching environment associated with engineering capstone to create the Engineering Teacher Belief Survey (or ETBS). As shown in Table 5 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 [49] . 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.

Table 5 Engineering Teacher Belief Survey (ETBS) Questions

	ETBS Question
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.

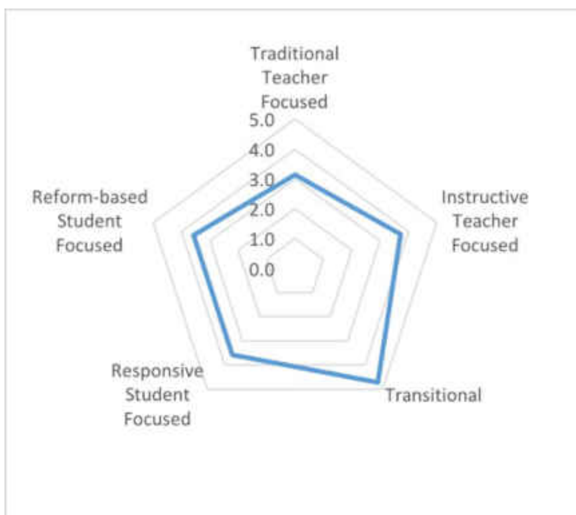

Figure 3 – Example Faculty Advisor ETBS Radar Chart

Programmatic Course Data

Complementing the CSPIS and ETBS data are various qualitative and quantitative student responses to course assignments used as a regular part of the capstone course. Traditional internal course metrics (i.e., project milestone grades, individual student contributions based upon peer evaluations, project preferences, etc.) served as a first-tier (screening) assessment of significant parameters. In addition, using inputs from project application forms and resumes, information about student project preferences, along with their skills and prior work experiences were factored into the analysis of each case study. The qualitative responses to the end of semester reflective memo assignment (see Appendix B) and peer evaluations (Appendix C) provided a longitudinal glimpse into how each project team progressed from the first to second semester, essentially providing first hand observations and calibration from students on their progress.

For a metric to quantify the level of engineering work experiences (i.e., internships, cooperative education experiences, etc.) the "engineering maturity factor" or EMF as defined by Steiner [17] was compiled for each student. The engineering maturity factor can be interpreted as follows:

- EMF = 2 → Coursework only, no engineering work experience
- EMF = 3 → One engineering work experience
- EMF = 4 → Multiple engineering work experiences

The sample data (Table 6) indicates that average GPA and EMF is highly correlated (r = .99).

Table 6-Engineering Maturity Factor and GPA Data

EMF	Ave GPA	No students	% students
2	3.12	121	46%
3	3.19	91	34%
4	3.33	52	20%
		264	100.0%

CHAPTER IV. CASE STUDY ANALYSES

The deeper insights into the character and complexion of the dynamic capstone educational environment are well-suited for the utilization of case study investigations, having used the screening process described in the previous section to extract characteristics of representative teams and faculty from the field of candidates. This selection process allows investigations of faculty mentoring methods from various classes of projects (i.e., faculty defined, student proposed, industry sponsored, university/research support) and faculty (i.e., tenured, research, lecturer and industry adjunct). Follow-on interviews emphasizing the selected cases allow for investigation 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" is desirable [51-53]. 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 documents, open-ended interviews, observational studies, structured interviews, as well as quantitative methods. 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 earlier, student data regarding skills, background, and perceptions of instruction were gathered via survey (i.e., the CSPIS) to provide a complimentary perspective. This is consistent with related prior work [39, 54]. Pembridge and Paretti introduced a taxonomy of capstone teaching characteristics that serve as a useful starting point for assessing faculty roles and student perception [13]. This taxonomy (and the associated survey tool) 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 team, knowing students' individual characteristics/habits/personalities, and prior industry or applied engineering experience

Both the CSPIS and ETBS serve to pursue additional data analogous to the course level Student Perception of Instruction (SPI) data in conjunction with assessing student satisfaction in the quality of various aspects of their educational experience (i.e., grades, instructional methodology, faculty, team, etc.)[39]. While the ETBS speaks to a faculty member's philosophy and approach, the CSPIS allows for insight into the student perspective of how that philosophy manifests itself in the faculty member's teaching methods. The pairing of the ETBS coupled with the CSPIS provides insight into how faculty belief translates into practice.

Each of the student project team case study summaries that follow consist of five to seven students for a total of 57 students out of the total population of 183 who responded to the CSPIS. Depending upon the case study, various faculty advisors may have had additional teams under their supervision that may have influenced CSPIS scores, which are acknowledged in the case study analyses that follow. As a backdrop for each of the case studies, the population median is included in each discussion for reference.

The case studies were performed against the backdrop of Type I - Faculty, Type II – Contextual and Type III - Student Influences. For each case study, faculty influences were analyzed based upon their ETBS profile aligned with the project team's CSPIS ratings. For the faculty-student (i.e., ETBS-CSPIS) alignment analysis the CSPIS ratings where organized into four areas consisting of individual student interests, technical guidance, teamwork, and design process, as follows:

Individual Student Interests

- My faculty advisor actively promotes my individual educational/engineering development.
- My faculty advisor adapts project guidance based upon individual student interests and capabilities.

Technical Guidance

- My faculty advisor is engaged in and aware of the technical aspects of my project.
- My faculty advisor helped guide the team in finding relevant technical information.
- My faculty advisor provided specific technical knowledge related to the project.

Teamwork

- My faculty advisor is invested in ensuring our team work environment promotes a healthy exchange of ideas.
- My faculty advisor helped maintain involvement and motivation for each individual student.
- My faculty advisor helped mediate or facilitate team interactions.
- My faculty advisor knows individual student contributions from team members.

Design Process

- My faculty advisor helped guide the development of project deliverables.
- My faculty advisor helped define/refine the project scope.
- My faculty advisor helped guide students through a structured design process.

There were two additional CSPIS questions that did not neatly fit under any of the other four areas which require some elaboration. In the first case, this is a general question which asks students about their perception of the faculty advisor as a professional role model and was used in the case study analyses for calibration with the other CSPIS questions. The median rating for the student population of faculty advisors as a professional role model was 3.92, with 5.0 maximum and a 3.58 minimum rating, indicating the students generally had a favorable perception of their faculty advisors as professional role models. The second question asks students to make a pointed decision about whether the faculty advisor favors an emphasis on technical accomplishments over student's educational development. The median rating for the student population for this question was 3.17, with a 3.25 maximum and 2.43 minimum value, indicating that students generally felt that their faculty advisors provided a balanced emphasis on project results and student education.

Case Study RUS1 – Research/University Support

Faculty Mentorship - Type I

Faculty Profile: The faculty advisor for this project was an early career (less than 10 years) academic professional. This individual has detailed context-specific knowledge that directly relates to the project. This faculty advisor has at least six years of continuous advising of senior design teams and was well calibrated to the structure of the course and with student project teams. As a data point worth noting, this faculty advisor was mentoring nine different senior design teams during the second half of the capstone process.

This faculty advisor self-reported symmetrically strong peaks (all 5.0) in Instructive Teacher Focused (ITF), Transitional (T), Responsive Student Focused (RSF), and Reform-based Student Focused (RBSF). The lack of skew in any particular area does not provide particular insight into this faculty advisor's approach or perspective. A slightly lower self-response (4.4) in Traditional Teacher Focused (TTF) does provide more insight. This faculty member is reporting that they believe they are in tune with student needs and are adaptive to individual learning paths, while also encouraging students to participate in their own educational development. This faculty member is self-reporting that they lean (mildly) away from the traditional lecture-based or TTF perspective.

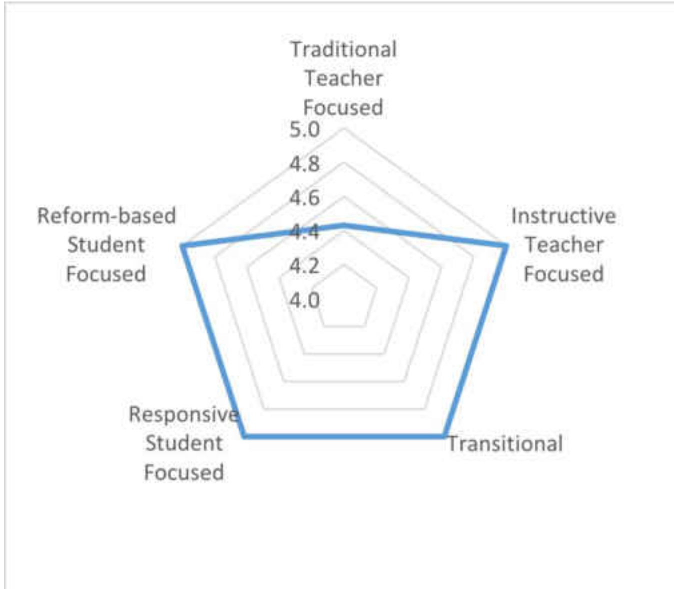

Figure 4 - Case Study RUS1 Faculty Advisor ETBS Profile

ETBS vs. CSPI: In this case, student-supplied survey CSPI data is somewhat contradictory to this faculty advisor's ETBS classification. Students reported that this faculty advisor did not provide substantial technical guidance, which is consistent with a lower TTF scoring. Unfortunately, this faculty member also self-reported beliefs that were RSF and RBSF, indicating that they were focused on student individuality and were responsive to individual student learning. Students reported that in their perception this faculty advisor did not have that same student awareness. However, students did report that the faculty advisor provided reasonable support in the design process area and did facilitate teamwork.

An emphasis on following process and performing as a team, while simultaneously not providing technical guidance or maintaining awareness of individual student activity implies a somewhat non-immersive awareness of team performance. Combined with the scenario that this faculty member was teaching other courses and mentoring nine teams, it appears that this faculty advisor expresses positive approaches, but is likely spread too thin to follow through.

Table 7 - Comparison of RUS1 CSPI Project Team to Faculty Student Population and Total Student Population Ratings

CSPI Category	Project Team CSPI Rating (this team)	Faculty-specific Student Population CSPI Rating (all teams)	Total Student Population Median
Individual Student Interests	2.92	3.26	3.56
Technical Guidance	2.63	2.80	3.59
Teamwork	3.29	3.27	3.47
Design Process	3.39	3.38	3.67

Context and Environment - Type II

Student Choice: Five of six students selected the project as their first choice, whereas one (of the six) students selected this project as their second choice.

Project Scope: This project was designed to have clearly defined scope, but had very ambitious goals for the design and execution phases. The team was asked to interface with an on-campus stakeholder who had conceived of the design problem. The stakeholder was both familiar with design methods as well as the capstone program deliverables and was able to provide structure consistent with both. This project should be described as "medium" scope, with fairly easily determined requirements yet ample room for creativity during concept development and system prototyping. This project required students to develop skills outside the traditional discipline-specific engineering curriculum.

Environment: Students were supported with all required analytical and design software, though students did report needing to learn this software without any particular guidance from university personnel. Students were able to accomplish all of their manufacturing and prototyping using on-campus resources. Students used stakeholder's supply/procurement process and did not report that finance/purchasing/logistics were any particular challenge.

Student Influences - Type III

Student EMF and GPA: Students in this project had an average EMF of 2.5, implying modest "real world" experience. Students on this team self-reported an average GPA of 3.15, which is considered slightly higher than average.

Student Motivation: Students reported mixed motivation at the start of the first semester. Several reported high initial motivation based on having been given their first choice, while at least one reported low motivation due to outside commitment levels (other classes, etc.). From the end of the first semester to the completion of the project at the end of the second semester, students indicated in their end of semester reflective memos that the main challenge to their motivation was internal issues with team dynamics and personality conflicts.

Analysis of Student Inputs:

This team's peer evaluations from the first semester indicated strong interpersonal conflict to be present on the team. Peer evaluations from the second semester were even more indicative of this issue. This team struggled with team dynamics for the entirety of the project, and it appears to be one of the main take-away learning points for this team. The quantitative evaluations in the team contribution area show the team broken into three pieces. One student who appears to have emerged as the team leader (scored generally high by most of the team), the main body of the team (modest and evenhanded scoring), and one team member who was uniformly very low-scoring (evaluated as failing by the team).

Searching for a deeper understanding of the challenges faced by this team, a more thorough assessment of the qualitative comments was performed. The comments were generally complimentary for the team leader, a mixture of complimentary and constructively-critical for the main body of the team, and uniformly negative for the low-scoring student.

As seen in other teams, their areas for improvement were all non-technical, focusing on communication, personality, work contribution/ethic, etc. The prevailing theme for this team's peer evaluation was a focus on the low performing student. Observations from the team included characterizations as follows:

- Loafing
- Misappropriation of other team members' contributions
- Combativeness

- Dishonesty with regards to work and time conflicts (including direct use of the word “lying”).

Review of the reflective memos was also of value in understanding the dynamics of this team’s performance. Comments and observations from the team during the first semester reflective memos indicated an appropriate challenge level for the project, and highlighted early technical achievements. There were definitely early indications of the issues that this team would go on to face in the second semester.

Notable quotes from first semester reflective memoranda:

- “I learned a lot about leadership and was able to apply the techniques learned in my leadership class.” (from the student who would go on to be the team leader)
- “The level of challenge this semester was just right.”
- “Need to improve on communication and expectations of team members.”
- “…arguments…group productivity to at least 50% of its original production.”

As with other teams, reflective memoranda from the second semester were more detailed as well as more expansive. The team reported generally being able to maintain motivation, but repeatedly cited intra-team conflict as being a negative influence.

One observation of note is that this team did not cite any Type II (i.e., contextual) issues for their second semester. There were no concerns associated with purchasing, logistics, manufacturing, or resources.

As previously stated, Type III factors were the most cited and influential for this team. Leadership, communication, and team dynamics were all included in the second semester reflective memos:

- "…making frequent trips [to campus] to solve team related issues…"
- "The thing I learned the most was to learn how to deal with team members who are not alike."
- "Helping each other was very crucial in this project…"
- "The biggest lesson I learned was how to deal with personalities that are very different than mine."
- "…effort level of the group definitely dwindled as our progress was upended by a difficult teammate."
- "…my lack of personal skills which might have caused friction between me and the group."
- "…most of the challenges that occurred for me this semester were ones dealing with my team members."

Case Study RUS1 Summary Observations

- The faculty advisor's self-reporting of beliefs largely did not translate to student recognition of those beliefs. Students reported that the faculty advisor provided adequate support for the course content and the design process, but did not indicate an awareness of student contributions and needs as individuals.

- CSPI Question 5, regarding whether or not the faculty advisor had characteristics as a potential role model was significantly lower than other teams.
- Students uniformly report modest technical successes and failures, but did not expound on possible solutions or further improvements.
- Peer evaluations are quantitatively consistent with the qualitative verbiage of the reflective memos, providing a valid confirmation (triangulation) of the observations.
- Review of the student peer-grading is generally consistent with the faculty advisor's grading. Students were much more willing to be heavily critical in peer evaluations, so the peer grading had a wider spread than the faculty grading.
- Some team members reported project management or technical successes/failures. Every team member strongly reported issues and concerns with team dynamics, team performance, leadership, communication, and accountability.

This team did not appear to consider their project a strong success. From the technical observations in their reflective memos, they clearly expanded their horizons and "learned to learn." Unfortunately, the prevailing tone of their summary memos is not overly positive.

Case Study FDP1 – Faculty Defined Project

Faculty Mentorship - Type I

Faculty Profile: The faculty advisor for this project is an early career (less than 10 years) academic professional. This project involves traditional principles of mechanical engineering, for which this faculty member has a thorough understanding. This faculty member's research and teaching interests are not directly aligned with the scope, nature, and character of the project. This faculty advisor has at least three years' experience advising senior design teams. This individual is well calibrated to the structure of the course and with student project teams. This faculty advisor has expressed difficulties in responding to teams with internal challenges and is challenged by teams that experience internal difficulties or have abstract design projects. This faculty advisor had equal ETBS peaks (4.0 score) in "Traditional Teacher Focused" (TTF) and "Transitional" (T). This faculty advisor has an excellent academic teaching record and is respected in the department for teaching traditional academic courses, which is consistent with the TTF paradigm. This also is consistent with the TTF belief structure.

This faculty advisor has a reputation for supporting student development, and has previously demonstrated an awareness of student engagement. These personality tendencies are in keeping with the transitional paradigm. The faculty advisor is willing to engage in adaptive or interactive activities when they are suggested, but does not proactively pursue those strategies. This aligns with the lower scoring in the RSF and RBSF areas.

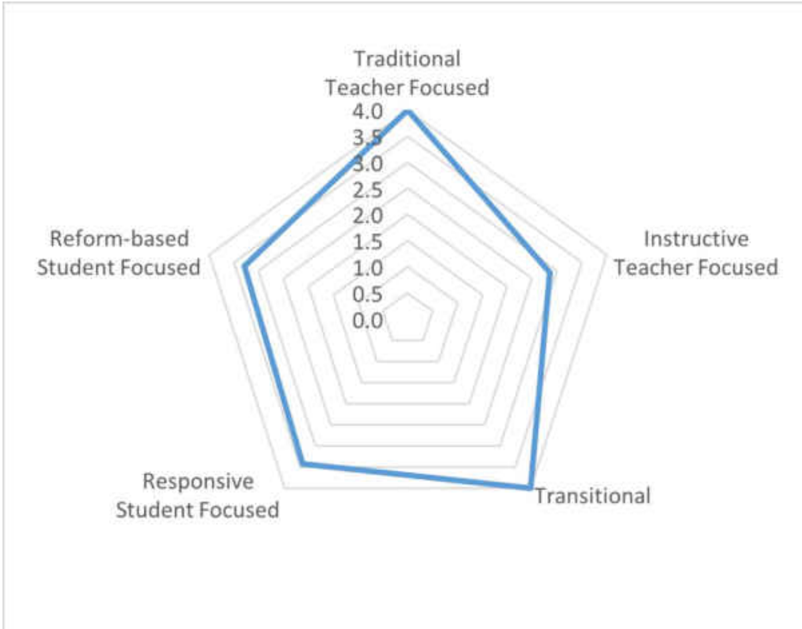

Figure 5 - Case Study FDP1 Faculty Advisor ETBS Profile

ETBS vs. CSPI: Student-supplied CSPI data is consistent with this faculty advisor's ETBS classification. This team evaluated the faculty advisor with roughly equal scoring in the areas of individual student interests, teamwork, and design process. This team is indicating that the faculty member maintained an awareness of student involvement, facilitated teamwork, and guided the team through the design process. The lowest score, technical guidance, was also consistent with this project being non-aligned to the faculty member's personal and professional strengths.

Table 8 - Comparison of FDP1 CSPI Project Team to Faculty Student Population and Total Student Population Ratings

CSPI Category	Project Team CSPI Rating (this team)	Faculty-specific Student Population CSPI Rating (all teams)	Total Student Population Median
Individual Student Interests	3.64	3.56	3.56
Technical Guidance	3.32	3.57	3.59
Teamwork	3.61	3.41	3.47
Design Process	3.71	3.64	3.67

Context and Environment - Type II

Student Choice: This project was one of the larger projects, with a team size of seven. Five of the students selected this project as their first choice, one as the second choice, and one as the third choice.

Project Scope: This project is an evolution of several previous projects. There were a number of pre-existing representative examples of the finished product. Consequently, this project can be defined as existing in a well-established design-space. This would have led to minimal ambiguity in the project scope, most student engineering teams would likely be able to make immediate traction. As a faculty defined project, there were no external organizational interfaces (sponsor, stakeholder, etc.). This project should be described as "medium" scope, reasonably accomplishable in the given two semesters by a team of 5-7 students. No new technology or development was required for this project, but knowledge synthesis from multiple core discipline-specific engineering topics was required. This project required a more substantial prototyping effort, which in the past has held broad appeal to many students.

Environment: Students were supported with all required analytical and design software. Students accomplished a limited portion of their manufacturing and prototyping using on-campus resources. This project required a much larger manufacturing footprint than the university could provide, and thus the prototype was largely assembled offsite. The team reported that this created challenges, since the majority of the team members were commuter students. The team also reported that budget and procurement were challenges to their effort during the second semester.

Student Influences - Type III

Student EMF and GPA: Students in this project had an average EMF of 2.57, implying modest "real world" experience. Students on this team self-reported an average GPA of 3.15, which is considered average academic performance.

Student Motivation: This project was initiated during a semester where there was not quite as much project diversity. Although this was a first-choice project for most students, several reported low motivation. Only one student reported high initial motivation.

Analysis of Student Inputs:

The grades assigned for the seven team members in the second semester ranged from very good to excellent. The project was overall successful and the team achieved their design objectives. As a regular part of the course, students were asked to evaluate each other for team contributions in areas of technical and project management contributions, and areas for improvement. The peer team contributions were consistent with the grades assigned, and the technical and project management qualitative comments were also consistent with the reflective memoranda. All seven peer evaluations were received, with six observations per peer evaluation.

The student peer observations paralleled the final grades assigned by the faculty advisor. This confirms that the faculty advisor was in touch with the performance of the team and vice versa; the students were too. Far more interesting, however, were the qualitative comments that the students made in conjunction with some of the lower-scoring data points. Of these other responses in the areas for improvement category, all fifteen list non-technical critiques and suggestions including:

- Better communication skills
- Too passive/need to be more proactive
- Procrastination / Need to take initiative
- Be respectful of team members / Learn to work as part of a team
- Be more dependable / accountable

Without trying to infer too much from any given observation, it is still noteworthy that every one of the comments involves team leadership, team dynamics, and communication. This trend was discernable early on in the project. There was very little reference to technical achievement or failure in the reflective memoranda for either the first or the second semester.

There were early indicators from the first semester reflective memoranda that were consistent with the peer evaluation comments:

- "…I found a lack of enthusiasm for this project. I found it to be meaningless…"
- "…not all people put in the same amount of work, or the same level of quality to their work."
- "…I had a teammate who was lazy."
- "Some failures included communication…"

This trend continued into the second semester, but the team was somewhat more positive in their comments:

- "I learned how to work together as a group and be more open to new ideas…"
- "…be able to say no to a teammate when [disagreement] but doing it with tact and respect."
- "…you can't always depend on people who are on your team."
- "…being able to work together very well."

- "…learning to compromise…"

- Multiple references to project management, scheduling, Gantt charts, etc.

It appears that this team experienced no substantive contextual challenges, and was appropriately supported by their faculty advisor. Nearly all of the substantive comments in their final semester reflective memos were team-oriented.

Case Study FDP1 Summary Observations

- The faculty advisor self-reported certain beliefs and philosophies of education (ETBS). Student CSPI data is consistent with the faculty member's philosophy. The faculty member is passively supportive of the student effort, but is not proactive in identifying unique instructional methodologies for individual students. The team was largely self-driven, with the faculty advisor providing encouragement and academic evaluation.

- On the topic of role model characteristics (CSPI Q5), this team reported an average Q5 response of 4. Combined with lower scores in technical guidance and higher scores in individual interests, teamwork, and design, it is observed that the students valued and respected their faculty advisor, but without a specific focus to their positive regard.

- Uniformly, students reported accomplishing certain tasks but did not cite advanced technical learning or speak of acquiring new skills. Much of their commentary was reserved for team performance.

- Peer evaluations are quantitatively and qualitatively consistent with the qualitative verbiage of the reflective memos, providing a valid confirmation of the observations.
- Review of the student peer-grading is consistent with the faculty advisor’s grading, implying students see the same performance as the faculty advisor (secondary confirmation of the academic evaluation).
- Some team members reported project management outcomes (both positive and negative). A few team members reported technical successes/challenges, but every team member strongly reported issues and concerns with team dynamics, team performance, leadership, communication, and accountability.

This team had a successful project. Students uniformly reported that their key learning points involved team dynamics, project management, communication, etc. Students appear to have had a satisfying learning experience requiring application of a broad array of engineering skills. Based on their comments in the programmatic data, the bulk of their horizon-broadening experience was in the teaming/collaboration area. This is consistent with other teams (all Type III influences).

Case Study SP1 – Student Proposed

Faculty Mentorship - Type I

Faculty Profile: The faculty advisor for this project is an early career academic professional with expertise and interest in engineering areas not directly aligned with the project. Nevertheless, the faculty advisor assigned had at least four years of experience advising senior design project teams and was well calibrated to the structure of the course and with student project teams. It was anticipated that this faculty advisor would be able to guide the students through the design process and be able to provide sufficient technical guidance for the students.

This faculty advisor had equal ETBS peaks (4.3 score) in “Instructive Teacher Focused” (ITF) and “Reform-based Student Focused” (RBSF). This implies that the faculty member is prepared to offer instructional content in a structured environment, which is consistent with their professional background and the ITF paradigm. The second peak in RBSF implies that this faculty member is also sensitive to the prospect of individuals learning independently of their peers. The ETBS indicates that this faculty member is likely perceptive to individual student performance as an indicator of personal development.

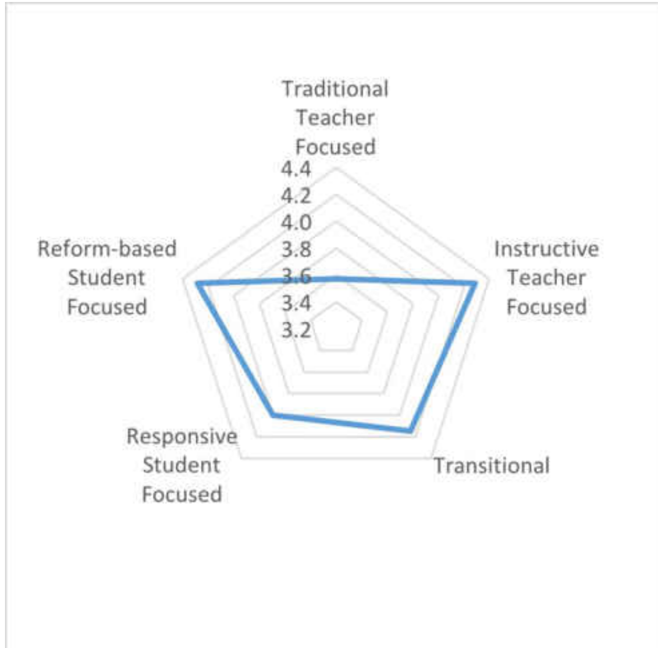

Figure 6 - Case Study SP1 Faculty Advisor ETBS Profile

ETBS vs. CSPI:

The alignment of this faculty advisor to this project was made as a course management decision. During the semester of project inception, faculty advisor loads were relatively high, and assignment of this project to the given faculty advisor was performed realizing that this may not be an ideal alignment (i.e., situation). This faculty advisor is experienced in the fundamental engineering principles underlying the project, but had no direct experience with the actual system being designed for the project. As a fairly experienced faculty advisor, the expectation was that the faculty advisor would be able to successfully guide the team through the design process.

Student-supplied survey CSPI data appears to support this expectation. This faculty member had a high peak (4.3) in the RBSF sector, indicating their beliefs in student individual learning. This faculty member also had a peak (4.3) in the ITF belief area, indicating they were comfortable in an instructional role as well as a facilitator role (RBSF). The trade-off of course is that a project that is not directly aligned to the faculty advisor's expertise or interest, may reduce their ability to focus their instructional orientations toward technical guidance.

Students reported the highest evaluation of the faculty advisor in the "design process" area, followed by "teamwork." It would appear from this feedback that the students felt that the faculty advisor was serving more in a project management or oversight role, facilitating the design process and ensuring that the team dynamic remained healthy.

As would have been expected from the beginning of the project, the lowest student-feedback rating was in the area of technical guidance, followed by individual student interests. This is consistent with past experience and programmatic expectations, namely that a faculty mentor would be far less likely to have technical insight into a design topic outside their core interests and expertise. Further, a lack of familiarity with the details of the design topic would imply a certain detachment from supporting and facilitating individual student interests.

Table 9 - CSPI Project Team, Faculty Student Population and Total Student Population Ratings

CSPI Category	Project Team CSPI Rating (this team)	Faculty-specific Student Population CSPI Rating (all teams)	Total Student Population Median
Individual Student Interests	3	3.66	3.56
Technical Guidance	2.6	3.59	3.59
Teamwork	3.1	3.44	3.47
Design Process	3.4	3.78	3.67

Context and Environment - Type II

Student Choice: All six students selected the project as their first choice.

Project Scope: This project was conceived of, proposed, and heavily advocated by students. There were several students involved as the original proponents, and these students recruited the balance of the team. There were many students interested in this project, and the final project participants all brought something extra to the table. This included hands-on skills, past experience with similar hardware, strong background in engineering fundamentals, etc.

The project was very challenging with ambitious goals. There were no external organizational interfaces defined by the University or the department. Members of the team were required to learn numerous new technical skills, including various types of analysis software, materials and manufacturing processes, chemical/metallurgical processes, and several types of testing and inspection. This project required excessive levels of manufacturing support (machining and fabrication) beyond a level which is typically supported by the department.

Environment: Students were supported with all required analytical and design software. Students were able to obtain adequate budget from the University, and obtained extensive support during the manufacturing phase. There were no comments (negative or positive) regarding the logistics and procurement process. Several students did observe that manufacturing, prototyping, and testing were more time consuming than expected. Additional feedback from knowledgeable technical professionals indicates this team had an unrealistically short prototyping/testing time window.

Student Influences - Type III

Student EMF and GPA: Students in this project had an average EMF of 2.67, with four of the six team members having had at least one type of project-based team experience. Students on this team self-reported an average GPA of 2.94 or average academic performance.

Student Motivation: Students uniformly reported extremely strong motivation to be present at the start of the project. All students reported remaining fairly strongly engaged throughout the project, with the main challenge cited by several students being outside time conflicts (i.e., work and other classes).

Analysis of Student Inputs:

Peer evaluations for this team show a reasonably balanced quantitative peer assessment. As a regular part of the course, students were asked to evaluate each other for team contributions in areas of technical and project management contributions, and areas for improvement.

This team's peer evaluations showed a team with fairly "flat" assessments in team contributions (i.e., little spread in the scores). Students who were evaluated positively by their peers were those who contributed to project management. Those who were evaluated lower were noted for areas of improvement such as level of involvement and recommending better communication.

As seen with other teams, the areas of improvement cited were all associated with team dynamics and team performance. The most commonly cited was a deficiency in communication, followed by lack of motivation/procrastination as well as an inability to follow deadlines (i.e., time management).

Review of the reflective memoranda was performed, and largely substantiated that this team was independent, self-driven, and successful.

Notable quotes from first semester reflective memos:

- "[project management role] helped me to understand the necessity of attention to detail and communication, as both factor heavily into project performance…"
- "I missed internal deadlines and procrastinated…"

- "…I have stepped up as the second project manager because I go above and beyond to make sure the team is on track."
- "…I need to work on my project management and interpersonal skills with people that I must work with."
- "Team chemistry was a vital factor…"
- "For my next design…I will be absolutely sure that the team works well together. This is a factor that my current team has, and I believe it to be a key to success."

As seen with other teams, reflective memoranda from the second semester were more detailed as well as more insightful. The students detailed being able to maintain their motivation level, with the primary distractions being outside work and other classes. The tangible hands-on experience of manufacturing their prototype was clearly a strong motivator for this team.

Reflective memoranda strongly referenced the team's successes, and cited learning of:

- New materials and fabrication techniques
- New analytical techniques
- New software skills
- Multiple references to non-classroom learning being appropriate and value-added.

The proportion of the reflective memoranda utilized to discuss the design/technical content was much higher on this team.

This team reported few failures and several significant successes, with the most notable again related to leadership, communication, and team dynamics (Type III factors):

- "Keeping all group members in the loop and asking questions in case I missed something potentially important helped keep us on track regarding goals and deadlines…"
- "…there is more I could have done if I had been self-motivated earlier in the project." [from the team member noted by peers as lacking motivation]
- "…gaps in communication…"
- "…this project taught me what it would be like to work on a team where everyone is responsible for their own small parts but must ultimately come together to create one working product."
- "My role as a group member was to organize meetings and pre-meeting agendas. I also helped create and implement the Gantt chart. I routinely referenced and updated it to help the team stay on track. I learned how to run a design process, work efficiently in a group, manage my time, communicate my ideas and present." [from the primary project manager]
- "Senior Design has taught me how to assess and manage a group of like-minded yet different individuals." [from the project technical manager]

Case Study SP1 Summary Observations

- The self-reported ETBS results are most applicable to projects where the faculty advisor is in an instructional role. This project was technically divergent from the faculty advisor's main areas of interest, and it was anticipated that the advisor would shift to an advisory/evaluation/project management role. That appears to be consistent with student-supplied feedback on what actually occurred.
- This project was aggressively scoped and challenging, but was also populated with a motivated group of students capable of independent work.
- Peer evaluations are consistent with student reflective memos, providing a valid confirmation of the observations.
- Review of the student peer-grading is consistent with the faculty advisor's grading, implying students see the same performance as the faculty advisor (secondary confirmation of the academic evaluation).
- Student self-assessment is remarkably candid and self-critical. Self-observations are also consistent with peer evaluations (both positive and negative), indicating that the students on this project are both self-aware and honest in their self-assessments.
- Students were able to speak of their technical achievements in detailed terms of learning, expanding their own skills, and specific project goals achieved. Students

tended to describe their peers more by their overall performance as a team member than on their technical work.

Overall, this project is a good representation of a project that went well. The challenge was real, students were consistently engaged, and the team stayed organized. As an independent team, they relied on their faculty advisor for guidance in the design process and to keep the team on an even keel, but did not look to their faculty advisor for technical guidance. Post-project comments are positive on design accomplishments, and openly self-critical on team dynamics (Type III) issues.

Case Study SP2 – Student Proposed

Faculty Mentorship - Type I

Faculty Profile: The faculty advisor for this project is a mid-career professional with expertise in both academia and industrial research. This faculty advisor has technical competencies and interests that align with various aspects of the project, and advised a modest number of senior design teams over the several years preceding this project. This faculty advisor was conversant with the structure of the course and familiar with principles of design.

This faculty advisor had the strongest ETBS peak (4.7) in the Instructive Teacher Focused (ITF) and the lowest scoring (4.1) in the Traditional Teacher Focused (TTF). The remaining fields all scored 4.3, also indicating a strong student-oriented philosophy. It would likely be anticipated that a faculty member with this cross-zone high scoring would be well engaged with students, and be perceptive to their individual developmental needs.

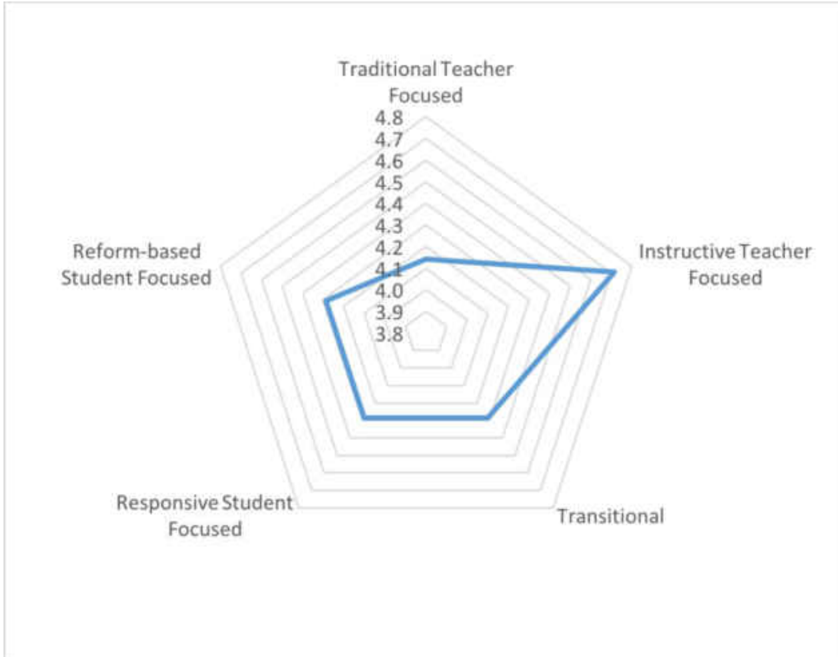

Figure 7 - Case Study SP2 Faculty Advisor ETBS Profile

ETBS vs. CSPI:

CSPI data collected from the student team (below) is consistent with the above expectation. Students reported the highest CSPI scoring in the area of individual student educational interests, followed by teamwork. Based on this data from the student team, it was their perception that the faculty advisor was aware of their individual work and facilitated an environment conducive to a positive team design effort.

Students reported lower scoring in the areas of design process and technical guidance. This project was student proposed, with strong project goals and a very independent team. This may have been a factor influencing the two lower scoring areas.

Table 10 - SP2 CSPI Project Team, Faculty Student Population and Total Student Population Ratings

CSPI Category	Project Team CSPI Rating (this team)	Faculty-specific Student Population CSPI Rating (all teams)	Total Student Population Median
Individual Student Interests	3.75	3.39	3.56
Technical Guidance	3.1	3.43	3.59
Teamwork	3.4	3.47	3.47
Design Process	3.3	3.67	3.67

Context and Environment - Type II

Student Choice: All seven students selected the project as their first choice.

Project Scope: This project was conceived of, proposed, and heavily advocated by students. Two students proposed the project and selectively recruited the balance of the seven-person team. Other students were interested in the project, but the five additional students were selected based on complimentary skillsets and a willingness to undertake an ambitious project.

As stated, this project was very challenging with ambitious goals. At initial conception, there were no external interfaces or stakeholders identified by the University or the department. The team identified a market sector (commercial viability) and contacted an appropriate external company. The students had the opportunity to work with the external company in an entirely self-directed fashion. Unlike other industry-sponsored projects where the faculty advisor serves as a liaison and point of interface, this student team managed their external contacts directly.

This project required a very broad and demanding skillset from the students, including mechanical systems design, metallurgy, thermodynamics and heat transfer, fluid and structural mechanics, manufacturing, and testing. The students on this project did not possess this entire skillset at the outset of the project, but as a team they successfully acquired an appropriate level of skill in each. The broad scope of learning required may have contributed to the lower CSPI on technical guidance, as these skills were largely self-taught rather than advisor-assisted.

Environment: Students were supported with all required analytical and design software. The students on this project were forewarned prior to project initiation that the scope of their project exceeded the ability of the University to support, either logistically or financially. The students on this project were able to obtain philanthropic support that allowed them to meet all of their prototyping needs. The students did not utilize University facilities for manufacturing and assembly, as the scope of the project exceeded availability. This team received technical and testing support from their external stakeholder.

Student Influences - Type III:

Student EMF and GPA: Students in this project had an average EMF of 2.71, with four of the seven team members having had at least one type of professional or project-based team experience. Students on this team self-reported an average GPA of 3.48 or high academic performance.

Student Motivation: Students uniformly reported extremely strong motivation to be present at the start of the project. All students reported remaining very strongly engaged throughout the project.

Analysis of Student Inputs:

Peer evaluations for this team were consistent on an individual basis. Specifically, each student evaluated the spread of the team fairly closely in terms of their evaluations. Between evaluators, however, there is somewhat more of a divergence in the evaluations. It was observed in this case that there was a greater tendency among the students who were early proponents of the project to more critically evaluate their team members. Whether this was an evaluator-calibration situation, or whether these student(s) had very high (possibly unmet) expectations is not determinable from the data. This does pose at least one observation for future study as to whether students who propose a closely-held project (to be pursued by a recruited team) are able to welcome the contributions of such a team objectively.

As previously indicated, there were a number of students recruited for this project based on their skills, academic and technical competencies, etc. What some of these recruited students lacked, however, were the practical applied skills and passionate topical interests of the project-proponent(s). Most of these recruited students reported that the project was scoped as a reasonable challenge level and they enjoyed rising to the occasion. Students reported that they enjoyed learning new and challenging technical topics, yet from the proponent(s) of the project there was a stated concern of having to “go back to the basics.”

It is apparent from both semesters’ reflective memoranda that while all students reported being motivated and interested in the project, there was a disconnect on the tempo, pace, and technical scope that was under investigation. This disconnect was reported in the reflective memoranda in terms of disappointment in project outcomes and team dynamics, poor communication, and missed expectations.

Areas of improvement noted by the team only reported a small number of occurrences of team members requiring more technical competence. These were reported by the team member(s) who were more technically familiar with the project topic as well as serving in a team leadership role. As might be anticipated, these were also the members of the team who were the strongest proponents of the project.

More broadly, the most dominant category cited in need of improvement revolved around communication, time management, participation, organization, and, very notably, lack of delegation. This last point bears emphasis, as it appears that this team was internally managed with a heavy hand and high expectations for the project by the original project proponents. Several students pushed the student team somewhat assertively. It should be noted that these same individuals also were stronger in their critiques of their team members at project conclusion.

Notable reflective memoranda quotes from the first semester:

- “Throughout the semester the project management was mostly distributed between me and [other project proponent]. Since it was [their] project…”
- “A success that we had was great communication…”
- “Our organizational skills were altogether not great, and we need to do a better job of clearly defining our goals and procedures.”
- “I learned a lot…about project management…”
- “I learned the importance of working together as a team and listening to a wide variety of ideas.”
- “One thing that worked was the use of a group chat…”

Moving into the second semester, the students reported good motivation as the project moved into the prototyping phase. The tangible hands-on experience of manufacturing their prototype was clearly a motivator for this team.

Reflective memoranda from the second semester were more detailed and expansive. Students were more willing to provide extensive and substantive comments regarding their project experience (both positive and negative).

Reflective memoranda modestly referenced the team’s successes, and cited learning of:

- New materials and fabrication techniques; corrosion
- New analytical techniques (FEA)

- Electromechanical integration
- Heat transfer, thermodynamics, and CAD/CAM.

In their second semester memoranda, the team reported various technical challenges but appears to have overcome most or all of those challenges. This content received only a small level of page-space in the memoranda, with the larger portion of the comments focused on team performance. These were generally categorized as Type III factors, including time management, communication and accountability, level of performance/engagement, and leadership style.

Notable comments from the second semester memoranda include:

- "Many of my team members were only moderately interested in the project…" (from a technical leader)
- "Learning involved with this project has been how to teach people and guide people while still allowing creativity for design on their part."
- "…terrible work ethic…"
- "I learned a lot these two semesters…about project management and teamwork."
- "One of the successes of the team was organization and dividing the workload."
- On describing successes: "putting together a team with different skill sets…with teammates that have similar workflow attitudes."

Case Study SP2 Summary Observations

- This team's perception of how they performed and how the team functioned was decidedly bipolar. Several people reported good communication and organization, and these were among the people who were rated by others as needing improvement in communication. There were comments on a good balance of work, and others regarding the poor work ethic of the teammates.
- As a whole, this team was internally driven and was not reliant on the faculty advisor for either technical guidance or project management. Students reported lower guidance from their faculty advisor as well. Whether this was due to students pushing forward on their own or whether the faculty advisor provided less direction is undetermined.
- This project was ambitiously scoped, and the motivation level of the team ranged from high to very high. Those students with the highest level of motivation did not report entirely favorably on their teammates.
- Review of the student peer-grading is consistent with the faculty advisor's grading, implying students see the same performance as the faculty advisor (secondary confirmation of the academic evaluation).
- Student self-assessment was limited, but there were some insights gained. Students who were assertive and/or dominant personalities (as reported by their peers) self-

reported a broader awareness of the importance of teamwork and task allocation during the second semester.

- Students were able to speak of their technical achievements in detailed terms of learning, expanding their own skills, and specific project goals achieved. Students tended to describe their peers more by their overall performance as a team member than on their technical work.

Overall, this project was a technical success, but one that has specific capstone-program ramifications and insights. This project was proposed by several students who were heavily invested in the project from the outset. These students ultimately did manage the project as leaders, but appear to have done so with a fairly heavy-handed style. This team does not present itself as a teamwork success, but rather as one or two driven students dragging their teammates forward and explaining project technical content to them. These "leaders" ultimately commented less-than-favorably on their peers, while those same peers reported that they learned and grew both technical and interpersonally. Given that the project team interacted with external stakeholders extensively, this team dynamic may not have been observed by the faculty advisor. This somewhat strong-willed behavior was, however, also directed at several University staff members.

This project was a technical success. Memoranda report that the team members did all grow technically and professionally. The nature of the team dynamic on this project raises questions as to whether this type of student-proposed project is best suited for capstone, but might instead be conducted through other university means such as a business incubator.

Case Study RUS2 - Research/University Support

Faculty Mentorship - Type I

Faculty Profile: The faculty advisor for this project is a mid-career instructor with significant industry and teaching experience. The project was a real-world engineering problem which was defined in support of University research involving engineering principles well aligned with the expertise and background of the faculty advisor. The faculty advisor is very well calibrated to the structure of the course and well versed with the facilitation of student teams. This faculty advisor is sensitive to the potential issues that can impact student teams and understands how to deal with those issues.

The faculty advisor had a low ETBS score of 2.0 in the Traditional Teacher Focused (TTF) area, but relatively high scores in all other areas. With high responsive and reform-based student focused scores (both 4.0), it is expected that this faculty advisor would demonstrate strong individual student and teamwork sensitivities. These qualities are complemented by a wealth of engineering knowledge and experience which in this case was well aligned with the project and freely shared with students.

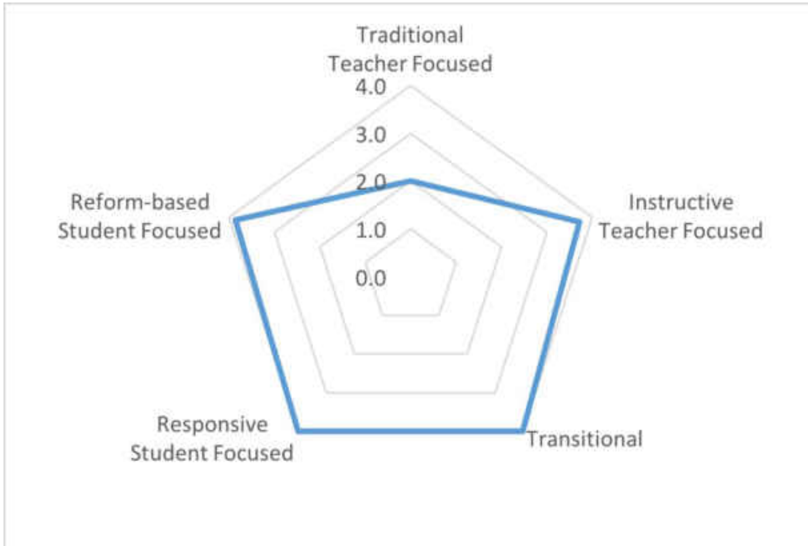

Figure 8 - Case Study RUS2 Faculty Advisor ETBS Profile

ETBS vs. CSPI: Student-supplied CSPI data is consistent with this Faculty Advisor's ETBS classification. This team evaluated the faculty advisor with relatively high scores in all areas of Individual Student Interests, Technical Guidance, Teamwork, and Design Process.

Table 11 - RUS2 CSPI Project Team, Faculty Student Population and Total Student Population Ratings

CSPI Category	Project Team CSPI Rating (this team)	Faculty-specific Student Population CSPI Rating (all teams)	Total Student Population Median
Individual Student Interests	4.6	4.6	3.56
Technical Guidance	4.6	4.6	3.59
Teamwork	4.3	4.3	3.47
Design Process	4.1	4.1	3.67

Context and Environment - Type II

Student Choice: All students assigned to this project had it as their first-choice project preference. The team consisted of seven students with participation from two disciplines.

Project Scope: The challenge level was relatively high involving a focus on system integration, manufacturing of advanced materials and final system test. Uncertainty on the part of the students in the early project definition phase had negative impacts on their motivation.

Environment: The team faced various challenges associated with obtaining technical support, materials procurement and locating appropriate space for building and testing during the second semester of the project.

Student Influences - Type III

Student EMF and GPA: The average EMF was 2.86 suggesting a fairly strong experience-based skill set. Only two out of seven students had no prior experience (i.e., internships, projects, etc.). The average GPA of the team was 3.18, indicating a good to very good academic standing.

Student Motivation: Although all students had first project preference, they expressed varying levels of motivation resulting from their perception that the project definition was “vague” and “uncertain”.

Analysis of Student Inputs:

This project team appears to be an excellent example of shared leadership in the face of a challenging and worthwhile endeavor. In this case, various students took on distinct roles in support of the overall mission in areas of analysis, manufacturing and project management.

Issues with project definition led to early motivation issues with the team. These early motivation issues, reflected in the comments below, indicated that the faculty advisor successfully remediated the issues with skillful team facilitation and support.

Noteworthy Student Comments:

- “The team got swept away by circumstances, past progress, and uncertainty instead of taking charge and feeling like the project was ours.”

- "Our design process has been fairly a-typical."
- "I was initially very interested and motivated by this project, partially because I wanted to learn more about systems integration, but as time went on I think the excitement of everyone on the team diminished."
- "When I found out that the scope of the project was really unclear and the quantity of resources somewhat limited, I lost some of my initial motivation."
- "What got me really motivated was the efforts of my group members and the desire to make good on the help we were receiving."
- "A category that I really struggled with, and could debatably be called a failure, is in the ordering system."
- "This semester I found myself much more motivated than last semester. There was hands-on work happening, which is very exciting."

Case Study RUS2 Summary Observations

- This team experienced serious issues with project definition during the first semester and "institutional" support 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 success.

- On the topic of role model characteristics (CSPI Q5), this team reported an average Q5 response of 5. Combined with high scores in individual interests, technical guidance, teamwork, and design process, it is clear that the students highly valued and respected their faculty advisor.
- One student had philosophical differences with the team in how they would operate. As a result, this student felt alienated from many of the technical aspects of the project. While the situation appears to have been a disappointment for the student, it did not appear to have a significant negative impact on overall student satisfaction or project results.
- Peer evaluations are quantitatively and qualitatively consistent with the student reflective memos, providing a valid confirmation of the observations.
- Student peer evaluations are generally consistent with the faculty advisor's grading.

This team faced some significant contextual issues, but with shared student leadership and excellent faculty guidance, they overcame obstacles and achieved a successful outcome.

Case Study IS1 - Industry Sponsored

Faculty Mentorship - Type I

Faculty Profile: The faculty advisor for this project is a mid-career academic professional with expertise and interest in engineering areas directly aligned with the project. This faculty advisor had modest prior exposure to mentorship of senior design teams. The faculty member had past experience with student design work and was considered well-calibrated to student performance expectations and capabilities. It was anticipated that this faculty advisor would be able to provide both technical and design guidance to the project team.

This faculty advisor had equal ETBS peaks (3.9) score in "Traditional Teacher Focused" (TTF) and "Reform-Based Student Focused" (RBSF). One interpretation of this combination would be that the advisor facilitates student learning via a structured instructional process combined with an awareness of the potential for student individual learning.

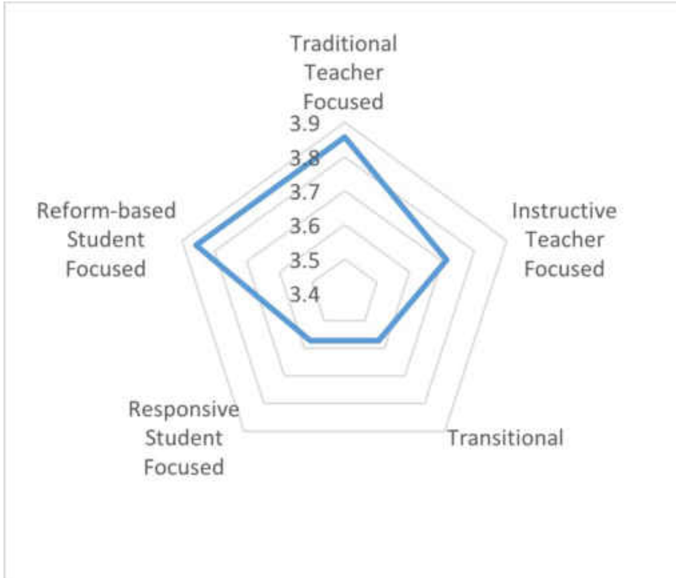

Figure 9 - Case Study IS4 Faculty Advisor ETBS Profile

ETBS vs. CSPI:

This faculty advisor was/is noted for their reputation as a thoughtful and supportive educator. The faculty advisor's assignment to this project was done with the expectation that the students would receive support and a strong level of engagement from the faculty advisor. The TTF and RBSF combination should have resulted in a thoughtful and considered engagement emphasizing and facilitating student learning. Students on this project team reported the highest CSPI score in Technical Guidance (4.1), indicating that this faculty advisor was in fact facilitating students' technical progression on the project. The second highest response area in the CSPI was in individual student educational interests (3.9), with the implication that the students perceived the faculty advisor as being aware of and invested in their work individually. This is also consistent with the RBSF paradigm.

Table 12 IS1 CSPI Project Team, Faculty Student Population and Total Student Population Ratings

CSPI Category	Project Team CSPI Rating (this team)	Faculty-specific Student Population CSPI Rating (all teams)	Total Student Population Median
Individual Student Interests	3.9	4.04	3.56
Technical Guidance	4.1	4.08	3.59
Teamwork	3.7	3.88	3.47
Design Process	3.7	3.92	3.67

Students characterized this faculty advisor as having provided a combination of technical guidance and awareness of individual student efforts, and this seems to have resonated with the project team. The team evaluated their faculty advisor on the fifth CSPI question (potential as a role model) with a rating of 4.2, indicating a fairly high level of regard for the faculty advisor.

Context and Environment - Type II

Student Choice: All seven students selected the project as their first choice.

Project Scope: This project was proposed and coordinated by an industry sponsor. The sponsor was familiar with the senior design program by virtue of recent past engagement with senior design teams, as well as personal experience as an engineer and entrepreneur. The project was well-scoped, with a medium difficulty level. There was clear communication of the project goals, but the project was defined broadly enough to allow for imagination and creativity in the solution and design.

Environment: Students were supported with all required analytical and design software. Students were able to obtain adequate budget from the University. One of the considerations for this project during the pre-kickoff scoping was to ensure that all manufacturing would be available to the students. There were no reports from the students of any substantial logistical issues in this regard.

Student Influences - Type III

Student EMF and GPA: Students in this project had an average EMF of 2.4 (modest), with two team members having had at least one type of professional or project-based team experience. Students on this team self-reported an average GPA of 3.54 (above average) academic performance.

Student Motivation: Students uniformly reported strong motivation to be present at the start of the project. All students reported remaining engaged throughout the project, with one exception. One motivator cited by the team was the relatively high level of engagement and support from the project sponsor. Several students did note that a detractor was their school load, work obligations, and commuting situation.

Analysis of Student Inputs:

Peer evaluations of this team did have modest variation. Trends were visible with regards to one or more team members, specifically in the area of time commitment and focus. One noteworthy observation is the student with the more frequent critiquing in this area was also the one student who noted their motivation was reduced during the second term. Where other students saw room for improvement, this student was refreshingly honest about changes in their own work ethic. Also noteworthy was that this particular student had high praise for the balance of the team.

The team's quantitative peer evaluations show modest variation in scoring, and the open-form qualitative observations on areas of improvement are fairly mild in temperament. These comments include scattered recommendations of focus, attendance, and awareness of demeanor. There are no references to technical deficiencies in the areas of improvement.

Faculty advisor grading of this team is consistent with the peer evaluations, providing high grades with mild variation that match the student observations.

A review of the reflective memoranda suggests that this team was motivated, but better yet that they were integrated into a cohesive team.

Notable reflective memoranda quotes from first semester:

- "The need for a set contract to abide by is certainly necessary."
- "A set structure to the team including an overseer/leadership position should be implemented."
- "Successes that will translate…team structure/organization…"
- "I learned that frequent communication and meetings are crucial to a group's dynamics."
- "I am fortunate to be with a group of respectful and kind members."
- "[meeting regularly] … helped our group have good communication and allowed our faculty member to always know the status of our project."
- "Administratively the team was able to establish a system of decision making and task-management that proved to be successful."
- "By the end of the semester, I believe I learned a lot about [project content] and project management."
- "…communication is the key."

Based on the types of comments noted above, this team appears to have been very well integrated and functioning well as a team by the end of the first semester. Review of second-semester reflective memoranda in this type of situation shows a tendency for functionallyintegrated teams to emphasize their technical achievements on the project, as there are few team dysfunctions for them to discuss.

This team's memoranda follow this pattern, with strong statements of technical accomplishment and what few failures noted are attributable to inexperience:

- Success noted in design (CAD, following a structured process)
- Success noted in analysis (self-learning, FEA, CFD)
- Failures/weaknesses noted in design-for-manufacturing due to inexperience
- Failures/weaknesses noted in assembly due to overlooking tolerancing (inexperience)

Notable reflective memoranda comments from second semester:

- "The team, overall, was full of like-minded individuals…"
- "The senor design project was probably one of the classes that I will remember and use the most for the rest of my life."
- "…we were a well-oiled machine…"
- "[unforeseen hurdles] can ultimately be solved with the combined effort of all team members…"
- "I am grateful for the amazing team that I had and for my sponsor and faculty member."

- "…every team member was involved to the end. I was blessed to have an amazing team to work alongside."
- "I have gained the confidence to be a team leader from this experience."

Case Study IS1 Summary Observations

- The faculty advisor assigned to this project has a reputation as a thoughtful and engaged educator. Student's end-of-project feedback is consistent with this reputation.
- This project was well-scoped, allowing for sufficient structure for guidance yet leaving room for design innovation.
- Peer evaluations are consistent with student reflective memos, providing a valid confirmation (triangulation) of the observations.
- Review of the student peer-grading is consistent with the faculty advisor's grading, implying students see the same performance as the faculty advisor (secondary confirmation of the academic evaluation).
- Students were able to speak of their technical achievements in detailed terms of learning, expanding their own skills, and specific project goals achieved. Students tended to describe their peers more by their overall performance as a team member than on their technical work.
- This team was well-integrated and serves as a positive example of highly functional team dynamics. Even those team members noted for lower performance were

evaluated generally positively, with team members providing positive feedback to complement deficiencies.

Overall, this project is a good representation of a project that went well. The project was a technical success, the team was engaged with only one or two minor exceptions. The faculty advisor and project sponsor played a positive role in facilitating student efforts, which was recognized by the team. This project and team dynamic should be noted as a potential example for future students.

Case Study IS2 - Industry Sponsored

Faculty Mentorship - Type I

Faculty Profile: The faculty advisor for this project is an experienced industry engineer with advanced academic credentials and a strong project management background. This faculty advisor has technical competencies in the areas related to the project and is familiar with the course structure. This faculty advisor is enthusiastic and engages with students well. This adjunct faculty member was hired specifically for the purpose of working with senior design teams, has worked with a handful of teams prior to this project, and continues to calibrate their professional experience against student performance.

This faculty advisor had a very strong ETBS peak as Transitional (T) with a 4.7 rating. This implies that the faculty advisor feels a strong need to involve the student in the educational process by directly engaging with the students. This is consistent with approaching team design work from an industry-centric philosophy. This stands in stark contrast to this faculty advisor's lowest ETBS rating of 3.1 in the Traditional Teacher Focused (TTF) area. This faculty advisor is not an academic course instructor, and the dichotomy between the low TTF rating and the high T rating is a strong statement of this perspective.

Figure 10 - Case Study Three Faculty Advisor ETBS Profile

ETBS vs. CSPI:

This faculty advisor has very high CSPI results in several areas. The advisor had dual peaks (4.8 out of possible 5) in both individual student interests and design process. This combined with a 4.5 rating in teamwork indicates that the students strongly felt that this faculty advisor was supporting their project in a structured fashion with their own specific individual and team interests in mind. Not surprisingly, the students also unanimously evaluated this faculty advisor with a 5 on the fifth CSPI question (having one or more attributes as a role model).

Student's lowest (but still good) evaluation was in the area of technical guidance (CSPI 3.8). An emphasis on student performance and design process with a lesser emphasis on specific guidance in technical areas is consistent with a project management faculty background. This combination of mentorship and guidance coupled with technical independence resonated with students based on their qualitative feedback in the reflective memoranda.

Table 13 - IS2 CSPI Project Team, Faculty Student Population and Total Student Population Ratings

CSPI Category	Project Team CSPI Rating (this team)	Faculty-specific Student Population CSPI Rating (all teams)	Total Student Population Median
Individual Student Interests	4.8	4.75	3.56
Technical Guidance	3.8	3.83	3.59
Teamwork	4.5	4.5	3.47
Design Process	4.8	4.83	3.67

Context and Environment - Type II

Student Choice: Five students selected the project as their first choice and two selected the project as their second choice.

Project Scope: This project was an industry-proposed project from a sponsor who has worked with senior design teams in the recent past. The project is a real-world extension of the project sponsor's business needs, and the representative of the stakeholder was available to engage with students and facilitate their understanding of the challenge.

This project was of medium challenge level, and provided adequate guidance at the initial project outset for students to gain an early understanding and find traction. All manufacturing required for the project was either made available by the university or the sponsor. The students were required to learn traditional manufacturing processes (and did so), but not required to develop new manufacturing techniques. The level of support for this team, both materially and logistically, was excellent.

Environment: Students were supported with all required analytical and design software. Students were able to obtain adequate budget from the University, and obtained appropriate support during the manufacturing phase. Several students did observe that manufacturing, prototyping, and testing were more time consuming than expected. Students did report manufacturing and prototyping delays due to typical manufacturing defects. Students were inexperienced at these methods and their delays were part of an experientially beneficial process (though frustrating to the students).

Student Influences - Type III

Student EMF and GPA: Students in this project had an average EMF of 2.71, with four of the seven team members having had at least one type of professional or project-based team experience. Students on this team self-reported an average GPA of 3.18, considered good academic performance.

Student Motivation: Students reported good motivation for the project, and appreciated the opportunity to engage with the representative of the sponsor. Motivation appears to have remained high among most of the team, with mild comments pertaining to work/class/commuting time conflicts.

Analysis of Student Inputs:

Peer evaluations for this team were not balanced, with a single individual being a specific outlier (i.e., a low rating). Most of this team supplied a fairly consistent medium-high assessment in the team performance quantitative assessment areas. The exception for this team was one individual who consistently scored at least two full points lower than the rest of the team. Qualitative evaluation in technical contribution and recommended areas for improvement revealed a similar pattern. The team was mildly complimentary of everyone except the individual previously noted. Student comments reveal a consistent description of social loafing combined with lower technical competency. Whereas most of the team seems to have performed cohesively, the team indicated that this one particular individual was frequently delinquent and made only minor contributions to the technical progress of the project, with at least one comment pertaining to falsification and deception. These student peer evaluations are consistent with the grading assigned by the faculty advisor. It would be expected that a faculty advisor with a project management background would be aware of individual contributions, and this turned out to be the case.

Specific comments from the team in recommended areas for improvement were directed at areas other than the basic technology/skills of the project content, and emphasized almost entirely Type III team performance factors such as work ethic, communication, timeliness, etc.

Review of the first-semester reflective memoranda was performed, with only a few minor comments of note:

- "…goals were related to communication in some way and I would say that the best take away from this semester was learning how to effectively communicate with other people with various experiences and backgrounds."
- "It would not be too bold to say that I have learned more in Senior Design than any other recent course I've taken at [institution]."
- "… our team began to become more familiar and trusting of one another, my motivation to work alongside my team members grew, not only to do well on the outcome of the project, but to support my fellow members."
- On topics learned: "Learning how to implement industry practices into a team, manage meeting times, and most importantly project management."

More than one student referenced that project motivation and success were due to the team effort. This is in contrast to a case of potential social loafing as noted above and could have led to addition internal conflict on the team.

A side-by-side comparison of all reflective memoranda from first and second semester led to one discrete observation and one trend. This type of side-by-side review is not required for grading and evaluation purposes, and it is unlikely that the faculty advisor would have observed that the alleged low-performer on the team submitted the exact same two-page reflective memorandum for the second term as was submitted for the first term (verbatim). Being cautious to not extrapolate from this observation, it is at least worthy to note that this individual declined to participate in the reflective self/team assessment performed by several hundred other students.

Comments made by other students were honest and reflected both successes and failures, as well as discrete learning-points. This team reported learning about manufacturing, CAD/CAM design techniques, microcontroller programming, and electromechanical controls.

Specific comments of note for the second-semester memoranda include:

- "I did face the challenge of getting less ambitious members to want to participate."
- "As project manager, I feel team morale is a huge responsibility I will be working on in future projects…"
- "I learned a lot about communication in groups, how important it is and what are some of the conflicts one can encounter while working on groups."
- "I take pride in watching others in the team grow and seeing others succeed."

- “I learned so much from this project, both technically and especially sociologically…The team faced many ups and downs and there were points where I could see the collapse of team bonding.”

IS2 Case Study Summary Observations

- The faculty advisor for this project was a career project management professional who expressed an ETBS philosophy of engaging students in the learning process. CSPI responses were strongly consistent with this instructional paradigm.
- This project was well-defined with a reasonable level of challenge for a team of this size and skill mix.
- Peer evaluations are consistent with student reflective memos, providing a valid confirmation of the observations, with the exception of one reflective memorandum duplicated from the first term.
- Review of the student peer-grading is consistent with the faculty advisor’s grading, implying students see the same performance as the faculty advisor (secondary confirmation of the academic evaluation).
- Students were able to speak of their technical achievements in detailed terms of learning, expanding their own skills, and specific project goals achieved.

- Student's second semester memoranda emphasized learning of team leadership as well as team/social and project management skills.

This project was a technical success. From a team perspective, the students faced challenges with a social loafing team member. While the faculty advisor was aware of the lower level of performance of this individual (as evidenced by final grades), this team could have benefited from a mid-project course correction. All members of the team held the faculty advisor in high regard for their awareness of student accomplishment and assistance in guiding the project trajectory. Post-project comments are mildly positive on design accomplishments and candid on the challenges faced by the team. Many of the technical challenges described by the team could have benefited from better communication and a more consistent team effort.

Case Study IS3 - Industry Sponsored

Faculty Mentorship - Type I

Faculty Profile: The faculty advisor for this project was an adjunct faculty member who is an experienced industry engineer with an advanced academic degree and expertise in systems engineering. This faculty member had more than five years of continuous experience advising senior design project teams with extensive professional experience that directly aligns with the main subject areas of the project. This faculty member was very familiar with the structure of the senior design curriculum and had a history of mentoring successful industry-sponsored project teams.

This faculty advisor had the highest ETBS peaks (4.71) in Traditional Teacher Focused (TTF) and Instructive Teacher Focused (ITF). This more traditional philosophy was somewhat in contrast to other adjunct(s) and reflects a more teacher-centric philosophy. This indicates that the faculty member likely placed greater emphasis on a structured instructional paradigm and less emphasis on individual student learning and development.

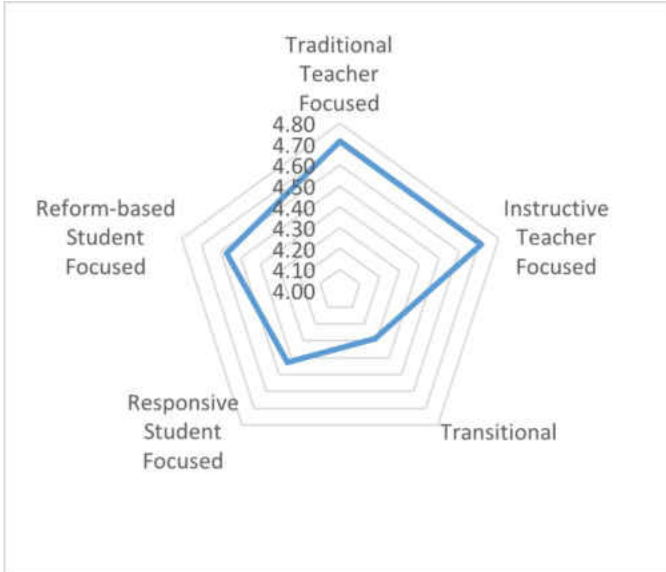

Figure 11 - Case Study IS3 Faculty Advisor ETBS Profile

ETBS vs. CSPI:

Students reported this faculty advisor's highest CSPI rating in the area of design process. Given that this is one of the areas of professional competency of this faculty advisor, this correlation is sensible. Lower responses in technical guidance and individual/team CSPI areas may be due to specific unmet student needs (reference discussion below). These student concerns are more fittingly aligned to contextual or team issues, but the students' responses indicate a lower level of support from the faculty advisor in addressing their concerns.

Table 14 - IS3 CSPI Project Team, Faculty Student Population and Total Student Population Ratings

CSPI Category	Project Team CSPI Rating (this team)	Faculty-specific Student Population CSPI Rating (all teams)	Total Student Population Median
Individual Student Interests	2.6	2.81	3.56
Technical Guidance	2.7	2.38	3.59
Teamwork	2.5	2.56	3.47
Design Process	3.4	3.00	3.67

Context and Environment - Type II

Student Choice: Five of the six students selected the project as their first choice, and one selected it the second choice.

Project Scope: This project was an externally sponsored project of modest scope. As is normal for externally sponsored projects, the original project description was drafted in conjunction with the sponsor. These project statements are typically brief introductions to the project and are intended to give students adequate understanding of the nature and character of the project for them to choose to engage. A typical next-step for student teams is to engage with the sponsor/stakeholder and develop more detailed requirements.

In this case, there were distinct issues associated with this follow-on engagement. Low levels of sponsor communication led to lack of clarity in the project scope and definition (context or Type II concerns). Consequently, students had a slow start verifying the original project scoping with the sponsor, and proceeded under a best-understanding of the sponsor's intent. Sporadic reconnection with the sponsor led to course corrections, scope creep, and scope change.

Environment: Students were supported with all required analytical and design software. Prototyping for this project would largely involve machining support, which was generally available from the university. Based on late-phase sponsor feedback on the project, this team requested significant support on a tight timeframe. In this case, the university was not able to supply this support due to limited personnel resources. Overall team accomplishments were limited by this chain of events.

Student Influences - Type III

Student EMF and GPA: Students in this project had an average EMF of 2.5, with three of the six team members having had at least one type of professional or project-based team experience. Students on this team self-reported an average GPA of 3.26 or good academic performance.

Student Motivation: Students reported strong motivation at the beginning of the project. The students were interested in engaging on a real-world project and expressed interest in seeing their work help solve one of the sponsor's problems. Limited communication from the project sponsor deflated student motivation levels.

Analysis of Student Inputs:

Peer evaluation for this team show a definite split. One half of the team reports continuing to work in the face of project scope uncertainty, while reporting the other half of the team as under-contributing. While varying in extent, there was a definite pattern to these evaluations. Of note, the three members of the team who were possibly underperforming also mutually evaluated each other as being lower performers. This pattern of evaluation was consistent with grading provided by the faculty advisor, though the student-provided grading assessment was more variable (higher spread).

Students were asked to evaluate each other for team contributions in areas of technical and project management contributions, and areas for improvement. Students who were evaluated positively by their peers were those who contributed to project management and engaged in leadership roles.

Those who were evaluated lower were noted for areas of improvement such as level of involvement (i.e., procrastination, non-attendance of meetings). Also noted were recommendations for improving communication. It should specifically be noted that not one student recommended a technical skill, technique, or approach for improvement, but that all recommendations were personally-oriented or teamwork-oriented.

Review of the reflective memoranda was performed and indicated that this team's project faced early challenges:

Notable reflective memoranda quotes from the first semester:

- “[sponsor] ignored or disregarded my emails.”
- “Something that did not work was waiting around for [sponsor] to tell us what they want.”
- “I do believe that communication both within our team and with our sponsor is something that can be improved upon.”
- “The two biggest challenge[s] for this semester…lack of motivation from my peers in the beginning of the semester and the lack of communication from our sponsor.”
- “…I was left a little disappointed.”

As seen with other teams, reflective memoranda from the second semester were more detailed. It is clear from some of the comments that the internal schism on the team had previously developed was even more pronounced:

- “Most of the work this semester was only from half of our team…”
- “…my motivation started to wear thin as I knew half the team was not making the same sacrifices…”
- “My biggest failure was not speaking up early when I noticed an effort imbalance, it only led to more work and stress in the long run.”

- "…it was extremely hard to encourage people to work more on the project when they refuse to learn the software needed."
- "...the lack of communication with our sponsor continued into this semester and made the team redesign the entire machine in [a month]. I now understand the importance of requirements."

Fortunately, however, even though this team struggled with focus and cohesiveness, there were some positive learning indications:

- "One of the biggest lessons that I learned this semester is how to effectively work in a group on a project such as this."
- "I learned so much during this year long project. I learned about company's expectations and how to communicate properly."
- "…I enjoyed working with a company like [sponsor] and believe the communication issues we had with them will make me a more effective communicator in the future."

IS3 Case Study Summary Observations

- The Faculty Advisor was experienced in design process and had a demonstrated ability to guide teams through successful projects. The faculty advisor did have schedule and time constraints due to commitments at their primary position.

- Contextual issues associated with initial project scoping were compounded by sponsor communication challenges.
- The team developed unhealthy internal dynamics, and demonstrated a lack of cohesiveness, a lack of trust, and poor communication.
- Peer evaluations are consistent with student reflective memos, providing a valid confirmation of the observations.
- Review of the student peer-grading is consistent with the faculty advisor's grading, implying students see the same performance as the faculty advisor (secondary confirmation of the academic evaluation). Students were more critical of their peers, with wider variance in their grading evaluations.

This project will be booked as a mixed-success project. This sponsor was not as 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.

This team was chartered with a brief project statement light on detail and were unable to obtain direction from their sponsor, through their faculty advisor, or through the senior design program staff. They reported that their motivation flagged and they did not "gel" as a team. When the sponsor was able to provide feedback at a later date, several students rose to the challenge while others did not, resulting in a divided and conflicted team.

The learning outcomes from this team will include a variety of technical achievements, but will also include a number of real-life lessons on interpersonal dynamics, trust, and communication (Type III issues). Programmatically, the faculty advisor and the senior design staff have worked to include a mandatory sponsor-communication plan into the curriculum for future teams. As unfortunate as certain circumstances faced by this team were, both they and the curriculum will have benefited from their experiences.

Case Study FD2 – Faculty Defined

Faculty Mentorship - Type I

Faculty Profile: The faculty advisor for this project was a senior academic professional with extensive expertise in the technical area of the project. This faculty advisor had only modest experience working with senior design teams under the current curriculum, but had extensive teaching and student-interaction experience to pull from in working with students. This faculty advisor was not an expert in engineering design, and it was expected that their interactions with the students would emphasize the technical topics more heavily than the design process.

This faculty advisor had a strong ETBS peak (4.9 score) in “Traditional Teacher Focused” (TTF) as well as a second high ETBS score (4.6) in “Instructive Teacher Focused” (ITF). This faculty member had an excellent academic teaching record and was respected in the department for teaching traditional academic courses. The faculty advisor’s distinguished career strongly emphasizing academic/classroom instruction which is consistent with the TTF/ITF combination.

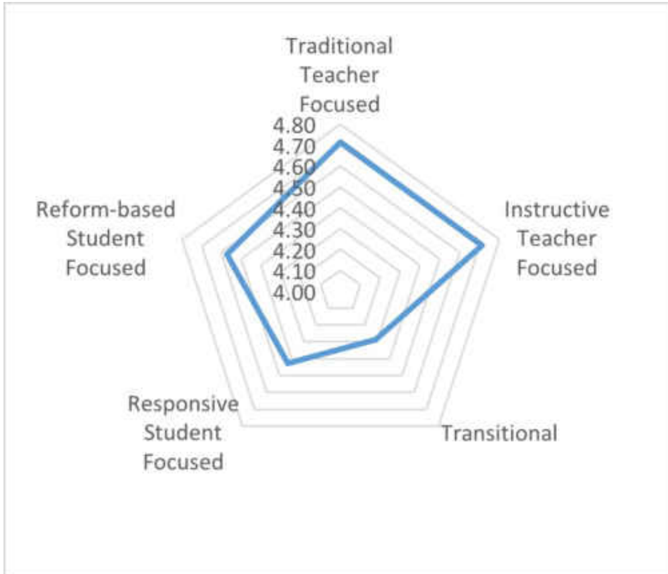

Figure 12 - FDP2 Case Study Faculty Advisor ETBS Profile

ETBS vs. CSPI:

This project called for a faculty advisor with specific technical competencies in the area of the design concentration. This faculty member had extensive experience in the fundamental technologies underlying the design and had a reputation for working well with students. It was expected that this faculty advisor would utilize their technical knowledge and instructional abilities to guide the technical aspects of the project. A lower level of instruction with the design process was anticipated and acceptable.

Student-supplied survey CSPI data appears to support this expectation. This faculty advisor was rated highly in awareness of teamwork (4.5 rating), indicating that students felt they fostered an inclusive team-oriented effort. Technical guidance and individual student support for individual student interests were the second rating (both at 4.1). As anticipated, students rated the design process guidance last, with a relatively high rating of 4.

From these CSPI scores, it would be anticipated that the student team would report a cohesive and healthy team environment with good feedback on faculty support. Indeed, this team unanimously reported a 5.0 rating for their faculty advisor as having characteristics as a professional role model.

Table 15 FDP2 CSPI Project Team, Faculty Student Population and Total Student Population Ratings

CSPI Category	Project Team CSPI Rating (this team)	Faculty-specific Student Population CSPI Rating (all teams)	Total Student Population Median
Individual Student Interests	4.1	3.83	3.56
Technical Guidance	4.1	3.60	3.59
Teamwork	4.5	3.59	3.47
Design Process	4.0	3.61	3.67

Context and Environment - Type II

Student Choice: All five students selected the project as their first choice.

Project Scope: This project was derived from a design challenge instituted by a professional organization. The senior design project derivation had been executed multiple times before this particular team was formed, leading to an excellent understanding of the project scope and character. This project was considered to be a light scope, appropriate for a team of four to six students to have a good learning experience without an exceptionally broad or deep technical challenge.

There were no external organizational interfaces defined by the University or the department for this project. Members of the team were required to learn numerous new technical skills, including various types of analysis software. Learning of new materials and manufacturing processes was limited to one or two new concepts. All required manufacturing capabilities were supplied by the university (performed by the team using university equipment). Prototyping and testing demands on this team were considered somewhat lighter than for many other teams.

Environment: Students were supported with all required analytical and design software. Students were able to obtain adequate budget and materials from the University, and obtained appropriate support during the manufacturing phase. Purchasing and logistics support appears to have been adequate.

Student Influences - Type III

Student EMF and GPA: Students in this project had an average EMF of 2.8, with three of the five team members having had at least one type of professional or project-based team experience. Students on this team self-reported an average GPA of 2.95 or good academic performance.

Student Motivation: Students uniformly reported good motivation to be present at the start of the project. All students reported remaining fairly strongly engaged throughout the project, with the main challenge cited by several students being outside time conflicts (i.e., work and other classes). Students reported that a hands-on experience was of importance in maintaining motivation levels.

Analysis of Student Inputs:

Peer evaluations for this team show a very consistent and very high quantitative peer assessment. There was unanimous positive regard, implying that there was no occurrence of social loafing on this team. Within the areas of team performance and support, any reduction from the highest level evaluation were scattered among the evaluation criteria (no distinct pattern). Areas of improvement for the team were mild comments on patience, openness of attitude, writing skills, etc.

Review of the reflective memoranda was performed, and largely substantiated that this team functioned well together, were organized, and successful.

Notable reflective memoranda quotes from the first semester:

- “I enjoyed the opportunity to discuss this design project with my peers whenever I could.”
- “...made easier through [team leader’s] efficient layout of our individual responsibilities.”
- “…as a group we helped each other from time to time and kept the project moving along.”
- “I have learned so much from this project and from this team experience.”

Reflective memoranda from the second semester were more detailed as well as more expansive and thoughtful. This team’s comments were positive and strongly team-oriented:

- “…learned a lot about professional teamwork.”
- “Being together helped out team more readily communicate ideas and issues, making it easier to overcome difficulties as a unit.”
- On success: “Great communication and division of labor.”
- “I have learned many things from this experience and probably the key takeaways would include strengthening my teamwork skills and learning how to handle adversity in a multitude of situations.”

Case Study FDP2 Summary Observations

- The Faculty Advisor self-reported ETBS beliefs that are most applicable to projects where the faculty advisor is in an instructional role. This project was consistent and compatible with that belief structure. Student-supplied feedback indicates this alignment was perceived and valued by students.
- This project was directly aligned to the faculty advisor's main areas of interest and expertise. It was anticipated that the faculty advisor would provide strong technical guidance, which students reported to be the case.
- The project was lightly scoped. Students reported modest technical achievements that evidenced professional growth and development.
- Peer evaluations are consistent with student reflective memos, providing a valid confirmation of the observations.
- Review of the student peer-grading is consistent with the faculty advisor's grading, implying students see the same performance as the faculty advisor (secondary confirmation of the academic evaluation).

Overall, this project is a good representation of a project that went well. The challenge level was reasonable, and the scope and nature of the project was more clearly defined, leading to early traction from the team. The team was able to obtain an appropriate level of design and technical guidance from the faculty advisor. This team reported a high-functioning team that demonstrated mutual support, interdependence, and good communication (positive Type III factors).

Summary of Case Study Analyses

For each case study, an in-depth multi-vector analysis was conducted, 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 16 below provides summary data from each of the case studies.

The summary data in Table 16 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 each case study analysis as follows:

4.0 → excellent

3.0 → good

2.0 → satisfactory

1.0 → poor

Table 16 Case Study Summary Data

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

General observations from the case study analyses revealed that faculty advisor engagement, clarity in project definition, and strong team dynamics, in combination, resulted in greater overall project success. 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.

It appears as if that lack of clarity in initial project definition can have a particularly deleterious impact on student success. For the case studies examined, two project teams (RUS1 and ISP3) had 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 after 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, there was 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, it can be argued that ensuring appropriate project scope and clarity in project definition is a faculty and program/department responsibility and can be identified as a type I/II interaction.

It can be noticed from the case study analyses 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, it was observed 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 attuned to these particular issues and aware of the appropriate interventions for remediation. In contrast, 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 the case studies, focuses on the issue of team dynamics and student leadership. As others have found [34], 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. From prior work [17] it can be observed 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. For the case study projects, general practice was 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 the case studies, it can be 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 [35], the case studies suggest that teams with shared leadership have more successful student outcomes and a more satisfying learning experience.

CHAPTER V. THEORETICAL FOUNDATION FOR EXPLORATION OF CAPSTONE PROJECT SUCCESS

A common approach for research in the area of engineering education is a statistical analysis capturing explicit relationships of the factors, interactions and response parameters. To be meaningful, the data set for this type of study would need to be large and reduce the scope of the research by focusing on specific measurable parameters, as seen in prior work [40, 55]. The focus of the research effort presented here took a decidedly different approach; designed to engage in a mixed methods analysis and assessment of case studies, obtaining deeper insights from the character and nuance of team and project context, without attempting to reduce the factors into an explicit mathematical formula.

Instead a generalizable model that can be applied to a broad cross-section of capstone projects has been developed. A principle goal of this research has been to identify functional relationships based upon case study observation and logical reasoning. Was the capstone project team successful or not? How do various conflating factors impact capstone course outcomes and how do they inter-relate? This chapter presents theoretical foundations based upon observations from the case study analyses and application of logical reasoning (Tables 19-23), expanding upon the logical schema presented in the overview of the research methodology presented in chapter 3 of this thesis (see Figure 2) and capitalizing on the issues impacting capstone project success presented in Table 3.

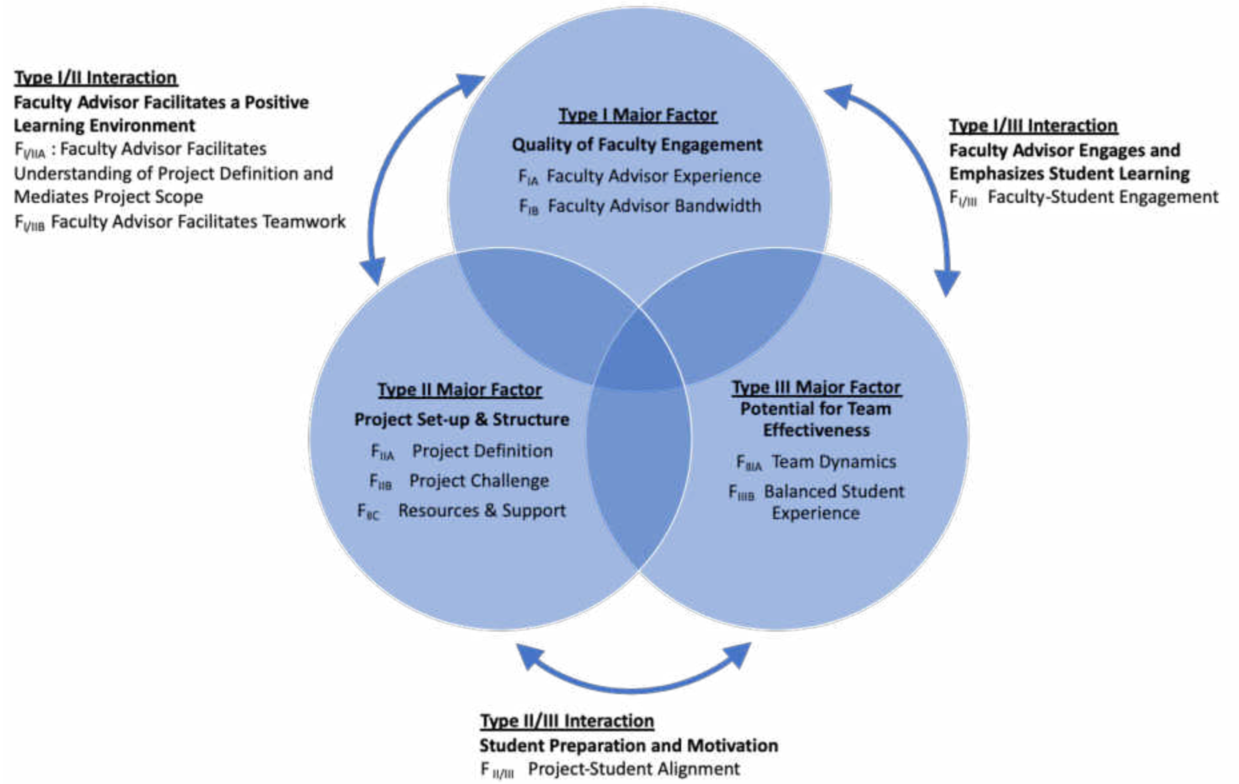

Figure 13 – Theoretical Foundations for Exploration of Capstone Project Success

This schema or framework allows for pooling of related sub-factors within the major factors of Faculty (Type I), Context (Type II), and Students (Type III), as well as consideration of the various interactions *between* the major factors. The objective is to formulate these functional relationships into a practical model for operational application. Drawing upon observations from the case studies, the following model for the probability of capstone project success ($P_{Success}$) is defined:

$$P_{Success} = f(\underbrace{F_{IA} \circledast F_{IB}}_{Type\ I}, \underbrace{F_{IIA} \circledast F_{IIB} \circledast F_{IIC}}_{Type\ II}, \underbrace{F_{IIIA} \circledast F_{IIIB}}_{Type\ III}, \underbrace{F_{I/II\ A} \circledast F_{I/II\ B}, F_{I/III}, F_{II/III}}_{Interactions\ between\ types})$$

Defining Sub-Factors

Sub-factors within each major factor have been observed to be related and this is represented with a conflating operator ⊛, implying that they are interrelated. Each of the seven sub-factors are derived from within one of the major factors. Each sub-factor is delineated in Table 17 and described in the following sections.

Table 17– Factors Influencing Probability of Project Success

	Sub-Factors	*Factor Type*
F_{IA}	*Faculty Advisor Experience*	*Type I Sub-Factor*
F_{IB}	*Faculty Advisor Bandwidth*	*Type I Sub-Factor*
F_{IIA}	*Project Definition*	*Type II Sub-Factor*
F_{IIB}	*Project Challenge Level*	*Type II Sub-Factor*
F_{IIC}	*Resource/Support Level*	*Type II Sub-Factor*
F_{IIIA}	*Team Dynamics*	*Type III Sub-Factor*
F_{IIIB}	*Balanced Student Experience (Skills, EMF, etc.)*	*Type III Sub-Factor*

Sub-Factor F_{IA} - Faculty Advisor Experience

Depending upon circumstances, various types of mentorship and advising can be valuable to different capstone project teams. Pembridge found that faculty teaching methodologies varied based upon the character and extent of the experience [13]. The faculty advising pool for this research involved career-academic faculty, industry-based adjunct faculty, and academic-industry hybrid faculty. Evaluation of the experience and skills of a diverse set of faculty advisors requires comparing and contrasting skillsets derived from varying experience bases. Rather than attempt to compare industry and academic experience, the emphasis for this factor was placed on the ability to bring experiences and skills to bear in a team-based learning (TBL) environment [56].

Sub-Factor F_{IB} - Faculty Advisor Bandwidth

The case study analyses clearly indicate that students were sensitive to the level of engagement of their faculty mentors. Faculty who were sincerely engaged, aware of individual student contributions, and able to manage their diverse responsibilities, and demonstrate such to the students, were more likely to motivate students and facilitate their success. Parallels were observed between the diversity, intensity, and complexity of faculty advisor workloads and the resulting impact on their ability to deeply engage. It was observed that faculty advisor availability and engagement was an important factor in their ability to support student teams.

The premise of bandwidth introduces the need to understand the volume of a faculty mentor's workload (full-time industry, full-load academic teaching commitments, research commitments, etc.). It also requires a deeper understanding of how complex and taxing those primary responsibilities are on the individual faculty advisor, as well as a deep understanding of personal limits on compartmentalization, multi-tasking, and other resource management techniques. From the case studies, it was observed that faculty advisors who have historically been among the best project advisors suffered a strong degradation in engagement as the number, complexity, and diversity of their commitments increased. This implies that in order to have effective advising, there is no "one size fits all" model of capability. Similar to matching students to projects, it is necessary to match faculty advisors to projects based upon interests and backgrounds.

Sub-Factor F_{IIA} – Project Definition

Project definition was a recurring theme in the students' reflective memoranda. Recalling that the projects arise from various sources (industry, faculty/university, students), the level of detail, clarity, and overall quality of project definition was observed to have a strong impact on students' ability to engage in an early and meaningful fashion. Prior work indicates that as initial motivation and excitement may wane, the ability of the students to clearly see their role is of motivational value [57] . Review of the reflective memoranda identified that clearly-written project definitions resounded with students, even if that definition was of challenging scope. In general, the observations from the case studies show that the students' ability to perceive progress (or a path for progress) is a meaningful motivator throughout the project. As noted in the summary of the case studies at the end of chapter 5, there was 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.

Sub-Factor F_{IIB} – Project Challenge Level

Again, recalling that the projects arise from various sources (industry, faculty/university, students), the overall character, nature, and therefore difficulty, can vary widely. Some projects may align directly to academic coursework, while other projects may require extensive research and personal development on the part of the students. From the case studies it was observed that student-conceived projects are sometimes not well-calibrated to the minimum expectations of a capstone program and that students appear to lack the awareness of scope to set achievable goals. Both faculty-research and industry-sponsored projects require similar calibration. Third-party stakeholders may not be well-calibrated to the competencies and capabilities of capstone students and thus may also set the challenge level too high [24]. High project challenge level may derive from multiple sources, such as depth of technical content (requiring "expert" level skills), breadth of technical content (multidisciplinary projects or projects outside the curriculum), or aggressive schedule (too much content packed into the capstone schedule). High project challenge level may also derive from unique prototyping requirements (machining, advanced manufacturing, sophisticated composite, synthetic or metallurgical processes, etc.).

Sub-Factor F_{IIC} – Project Resource/Support Level

Initial efforts to define influencing factors did not identify this factor. The capstone program against which this study was conducted has several screening processes for projects to be accepted and approved. One of those screening factors is a regular discussion of whether or not the university has the resources to help students execute a project. For that reason, most of the case study projects did not have insurmountable discrepancies between resource needs and the available support. Nevertheless, further analysis indicates that an existing ad-hoc process should not mask an important parameter, and indeed, that the process should be formalized and made more robust.

Some resource challenges were overcome years prior to this work and thus were never mentioned by the teams in the case studies. Drawing on past challenges beyond the case studies, these already-met resource challenges included meeting space, schedule flexibility, computer lab support, and availability of analytical/engineering software licenses. Drawing from the case study analyses, continued existing challenges include budget, supply/purchasing administrative hurdles, fabrication and testing facilities/space, and availability of unique manufacturing services (machine shops, additive manufacturing, laser cutting, etc.).

Past projects which required substantial resources historically were screened by the ad-hoc process of project approvals, but ill-defined, poorly-scoped projects (or projects with scope creep) evaded this ad-hoc process and later caused extensive challenges to students' efforts. A more rigorous and well-defined assessment of resource requirements is perceived to be a strong factor in this theoretical model.

Sub-Factor F_{IIIA} – Team Dynamics

Capstone design projects are fundamentally a team-based learning experience. Recurring themes in each of the cases studied dealt with issues of team cohesiveness, interdependency and collaboration of team members, as well as overall communication and leadership. Extensive feedback from individual students, via their peer evaluations and reflective memoranda, is described that focuses on teamwork issues. Early efforts in the team-formation process emphasize aligning students to their projects in order to capture their interest and motivation, but the process does not emphasize past collaboration history. This process is utilized in keeping with the philosophy that capstone is intended to be a transitional experience or bridge from the academic career into a professional career. As students will likely not have the opportunity to select their coworkers with employment, it is perceived that there is experiential value in learning to develop communication skills, collaboration, interdependence, and teamwork. Sadly, there is also educational and professional value when these traits do not manifest [24]. While student self-selection and smaller team size can serve to mitigate teamwork issues, such remediations are not entirely in the spirit of providing students with a real-world culminating experience. As an educational philosophy it can be maintained that challenging students to develop teamwork skills is a critical life-experience benefit of capstone.

As such, the most successful project teams in the case studies demonstrate that positive team dynamics are not a given and an effort needs to be made to facilitate and engage team-building through-out the capstone design culminating experience.

Sub-Factor F_{IIIB} – Balanced Student Experience

Prior to project team formation, students are given the opportunity to "bid" on projects of interest. It is common practice for instructors to assign students to project teams based upon various criteria, one of which is project preference [20]. From these project requests, teams are formed based on the number of students desiring a project as well as the number of team-member slots available. This process requires sifting through many student applications and sorting them based on preference, skills, and abilities. The process emphasizes evaluation of students based on a skills inventory relevant to their discipline(s), as well as an evaluation of their past experience, internships, and co-ops (i.e., the Engineering Maturity Factor, or EMF). The process emphasizes balancing each team with at least one or more students with past work experience. Seeding teams with students having past engineering experience and then complimenting those students with other team members with compatible interests and complementary skills has served to craft generally balanced teams. It should be noted that this methodology only speaks to balancing past experience and technical skills, and does not address motivational issues (e.g., social loafing).

Defining Interactions

The interaction factors represent phenomena outside and between the major factors, where one major factor (i.e., faculty, context or student) was observed as having the opportunity to impact another major factor. Each of the four interactions were identified from the case studies and are delineated in Table 18 and described in the following sections.

Table 18 – Interactions Between Factor Types

$F_{I/II\ A}$	*Faculty-Context (Faculty facilitates project definition, Mediates project scope)*	*Type I/II Interaction*
$F_{I/II\ B}$	*Faculty-Context (Faculty Advisor facilitates Teamwork)*	*Type I/II Interaction*
$F_{I/III}$	*Faculty-Student (Faculty Advisor engages and emphasizes student learning)*	*Type I/III Interaction*
$F_{II/III}$	*Student-Project Alignment (Students are prepared and engage with the project content)*	*Type II/III Interaction*

Faculty-Context Interaction $F_{I/II\ A}$ – Faculty advisor facilitates project definition and mediates project scope

This type I/II interaction was identified as an opportunity for faculty to either create or define project context. The case studies indicate that a clear (and early) definition of project scope (Factor IIA) is important. In the case of the capstone program for which this study was executed, the projects are delegated to the supporting faculty advisors. Those faculty advisors then have the opportunity (and responsibility) to create goals and milestones to challenge the students. The primary tool those faculty advisors will use is a continuous monitoring of project objectives and scope, ensuring that students are adequately challenged and not over or underwhelmed. The interaction between the faculty advisor and the project scope allows for adaptation and customization, and implies that the faculty advisor retains the ability to modify the project context.

One insight provided by the data collected via the CSPI survey was a growing awareness that just as students engage with each other and with the project, faculty advisors similarly engage with projects and student teams based on the character and nature of the projects. Project technical content may be directly aligned with the faculty member's area of research (for academic faculty) or professional interest (for industry mentors). Project scope and challenge level may also be alignment parameters (experienced mentors aligning to challenging projects, etc.). General practice is to align faculty mentors to the technical content of the project as a matter of course management. Industry-sponsored projects have added complexities associated with project management, external sponsor liaison interactions, and sophisticated prototyping and systems evaluation/testing. Factor $F_{I/II\ A}$ largely condenses down to a single question: Is the faculty advisor sufficiently comfortable with and knowledgeable of the project content to confidently and pro-actively make course-corrections over the project performance period in order to maximize student learning?

Faculty-Context Interaction $F_{I/II\,B}$ – Faculty advisor facilitates teamwork

Team dynamics, previously described as F_{IIIA}, was one of the areas where students expended the most time and effort discussing their capstone experiences in their end of semester reflective memoranda. Teams with a positive work environment were observed to be more willing to share ideas, collaborate, and interact in a healthy and positive fashion. This type of environment was observed to allow for team cohesion and allowed for team members to take advantage of each other's strengths, becoming greater than the sum of their parts. The most important aspect of $F_{I/IIB}$, however, is that the faculty advisor does not only have the opportunity to monitor the team working environment, but actually has the opportunity to *create* it. Strong management skills, team mediation experience, and past personal experience in multiparty/team projects were seen in the case studies as evidence of faculty mentors actively creating a healthy work environment. There is some anecdotal evidence that this ability is tempered by F_{IB} (Bandwidth), namely that faculty advisors reaching their workload limits may not be able to monitor/mediate and create this positive influence. Awareness of $F_{I/IIB}$ faculty-context interactions is a strong argument for carefully monitoring advisor workload, as quality of advising may suffer accordingly.

Faculty-Student Interaction $F_{I/III}$ – Faculty advisor engages and emphasizes student learning

Faculty-Student interactions are perhaps one of the most delicate discussion points of this theoretical model. The ability to engage with students, motivate them, and enable their success based on individual needs is a deceptively simple concept in theory, and is much more difficult in practice. The issues previously described in Chapter 2 of this thesis provide an extensive list of past observations about how a faculty advisor might not provide engagement and support. A more constructive approach is to emphasize positive interactions. Faculty mentors bring to the table their professional backgrounds, their attitudes towards education (as evidenced by the ETBS), and their demeanor and personality. Students bring to the table their individual and collective EMF and abilities to manage team dynamics. Each student project team will have needs and demands of the faculty advisor. A team may need project-specific technical guidance, design practice guidance, or may be self-directed and need only academic evaluation. Many teams experience challenges with team formation and team dynamics and require coaching and team facilitation. The CSPI data, collected from students that were approaching the end of their projects, is one area where visibility into the dynamic between individual and team needs, as well as the engagement of the faculty mentor is apparent. Hypotheticals in this case include:

- Does the faculty advisor appreciate the need to maintain student motivation?
- Does the faculty advisor engage individually and understand the contributions of each student?
- Are expectations reasonable? Are goals discrete and actionable? Do students receive guidance and feedback (positive affirmation or constructive criticism, as appropriate)?
- If the team needs design practice advice, is the faculty advisor able to provide it?

- If the team needs technical advice/guidance, is the faculty advisor able to provide it?
- If the team needs project management, team facilitation, or stakeholder liaison support, is the faculty advisor providing it?

In short, the needs of the team can vary by team (and project) and the faculty advisors in some cases need to be a catch-all supplier of mentorship and management. In the case studies assessed, each of the above scenarios (and more) occurred.

As a diagnostic tool, the ETBS tool captured data on the faculty advisor belief structure, and surveys from the students (the CSPI) helped ascertain how well those beliefs were put into practice in supporting student project success. The ETBS provides one candidate tool for aligning faculty roles to student learning objectives, and the CSPI provides an opportunity to monitor the quality of student-faculty interactions.

Context-Student Interaction $F_{II/III}$ – Students are prepared and engaged with the project content

As previously described, team formation emphasizes student project choice, working under the premise that promoting student motivational engagement on projects includes allowing input on project choice. Teams are formed based on balancing experienced members (higher individual EMF) with members of lower experience (blended experience teams).

However, during the case study analyses, it was noted that not all students are academically and experientially prepared for all projects (preference notwithstanding). Observations from the case study analyses suggest a more rigorous assessment of student candidacy for projects and matching discrete skill requirements (or goals) of the project against student qualifications could significantly improve capstone success and student satisfaction. A goal of this assessment would be to balance student educational growth against student-project skill gaps. Challenging students is the goal, yet overwhelming them is counterproductive and destructive.

Student-project engagement was a significant influence factor noted during the case studies. The population set evaluated during the case studies was inclusive and diverse in terms of behaviors manifested. Student failure to engage with the project content took the form of unprofessional behavior, over commitment and time conflicts (e.g.s., high course load, family responsibilities, extracurricular activities).

In contrast to the well-known issue of social loafing, the case studies also surfaced the interesting and opposite phenomenon of “socially dominant” behaviors. Whereas the archetypical social loafing student is a “slacker” who does not engage, misses meetings and does not deliver on work commitments, there were several observances of socially dominant or hyper-assertive students. These students were observed to be highly engaged, assertive, and generally having low tolerance for normally-performing, underperforming, or socially loafing students. Socially dominant students were seen to take the weight of the world on their shoulders, bearing the brunt of the project work, and often not constructively working to resolve the internal team dynamic that created the imbalance in the first place. While the result of this phenomenon (i.e., frustration and conflict) is felt in the team dynamics (Sub-Factor

F_{IIIA}), these students typically demonstrate this characteristic before team formation and thus socially domineering behavior may be considered a pre-existing "contextual" characteristic.

Reduction of Factor, Sub-Factor and Interaction Conflation

The case study analyses exposed seven sub-factors and four interactions between the three major factors of faculty, contextual and student influences. The theoretical framework presented has woven the various threads of capstone understanding into a rich and complex tapestry. While the factors themselves may seem clear, in practice the "conflation" or mixing between sub-factors and interactions between the major factors has the potential of making capstone program planning using the framework challenging, so an effort has been made to resolve the sub-factors and major factor interactions into a reduced set, with the intent of making the theoretical foundations for capstone success more meaningful and actionable.

Resolving Conflation in Type I Sub-Factors: F_I – Quality of Faculty Engagement

Recalling F_{IA} (faculty advisor experience) and F_{IB} (bandwidth), a focus is placed on the first instance of conflating factors:

$$\underbrace{F_{IA} \circledast F_{IB}}_{Type\ I}$$

The faculty advisors associated with the nine case studies were a subset of the project mentors affiliated with the program (both currently and historically). Nevertheless, the case studies served to highlight and illuminate the impact of faculty skillsets and contributions. Faculty advisors with extensive experience in a relevant area (either industry or academia) appear to have greater ability to anticipate student needs, and faculty with reasonably calibrated engagement are seen to have the time and bandwidth with which to apply that perceptive anticipation. Experience without bandwidth (an overloaded, experienced faculty mentor) is of one type of concern, while an inexperienced yet available (low workload) faculty member with time, but not skill is a different concern. These observations have meaningful impact on faculty advisor selection and training, and carefully assessing the balance between the two parameters requires ongoing information regarding activities beyond the basic capstone activity (evolving faculty resumes, time commitments, etc.).

As a resolution of the two Type I sub-factors, it is proposed to introduce a single factor "Quality of Faculty Engagement" in place of the two Type I factors as represented in a parametric or Boolean "And" fashion below.

Table 19 – Quality of Faculty Engagement

F_{IA} – Faculty Advisor Experience	F_{IB} – Faculty Advisor Bandwidth	F_I – Quality of Faculty Engagement
Low	Low	Low
Low	High	Low
High	Low	Low
High	High	High

This dissection of the complex interaction provides value in two important ways. First, the observation of the quality of faculty engagement is consistent with all of the case studies and with the student feedback from the CSPIS. Second, each of the non-desirable "low" results has identified the potential for specific remediations and interventions.

Resolving Conflation in Type II Sub-Factors: F_{II} – Project Set-up and Structure

Recalling F_{IIA} (Project Definition), F_{IIB} (Project Scope), and F_{IIC} (Resources/Support) a similar investigation is performed on the Type II sub-factors:

$$\underbrace{F_{IIA} \circledast F_{IIB} \circledast F_{IIC}}_{Type\ II}$$

The two contextual (Type II) factors observed to create the most impact were the detail, clarity, and quality of the Project Definition (F_{IIA}), as well as the Project Challenge Level or difficulty (F_{IIB}). As previously discussed, the structure of the existing program typically ensured adequacy of resources (F_{IIC}). A recurring theme in the case study analyses was the positive attitudes and general satisfaction of students with certain combinations of these two factors (Definition/Challenge).

In an effort to expand the utility of the findings and create guidance for specific, needful interventions, a Boolean resolution similar to the Type I effort was prepared based on observations from the case studies. For clarity, consider the following questions in conjunction with Table 20:

- Is the project clearly defined? Are goals and objectives clear?
- Is the project challenge level calibrated to student capabilities?
- Are appropriate resources available to support project success?

Table 20 – Project Set-Up and Structure

F_{IIA}–Project Definition	F_{IIB}–Project Challenge	F_{IIC}–Resources/Support	F_{II} – Project Set-up and Structure
False	False	False	Low
False	False	True	Low
False	True	False	Low
False	True	True	Low
True	False	False	Low
True	False	True	Low
True	True	False	Low
True	True	True	High
False - Poor/Unclear True – Good/Clear	False – poorly-calibrated True – well-calibrated	False - inadequate True - adequate	Low Potential for success High Potential for success

As observed from the case studies, projects that were very clearly defined had higher levels of student satisfaction. Clarity of project definition (F_{IIA}) in the earlier phases of the design challenge allowed students to gain traction earlier, fostered positive interactions, and led to healthy team dynamics. Combined with well-calibrated challenge levels (F_{IIB}), these projects set meaningful and achievable goals for project teams, leading to positive feedback and a sense of accomplishment. When these types of projects were supported with adequate resources (F_{IIIC}), barriers to student progress were removed resulting in unimpeded progress. The (F_{IIA}, F_{IIB}, F_{IIC}) combination of (True:True:True) is clearly the optimal combination of contextual factors resulting in a high probability of success.

Each of the other seven combinations have lower probability for success, and each has its own discrete set of hazards and failure modes. Drawing from an organized Failure Modes and Effects Analysis (FMEA) process is one approach to understanding the potential flaws in each scenario.

Projects that were clear in definition but more difficult (True:False:True) had some potential for success, but the observation from the case studies was that while some teams were willing to rise to the challenge of a very difficult project, this was unpredictable and unreliable. Critical in this combination was a perception of early efforts as meaningful and successful. Early traction on the project had the potential to lead to continued engagement and a continuation of efforts in the face of a difficult project.

Projects that were unclear in definition but of reasonable challenge (False:True:True) were also observed to have some potential for success, but the clarity of project objectives was typically resolved after team formation and was dependent on intervention by the faculty advisor. Since the home program for this study uses a distributed advising model, this delegation of responsibility for project clarification had mixed results.

The main cautionary (negative) outcome of the Definition/Difficulty combination rests in poorly defined or ambiguous projects of challenging scope (False:False:True). Teams with unclear goals or project statements who also had challenging projects were observed in projects affiliated with industry and research-supporting projects. External entities were observed to sometimes not provide clear project objectives, and were not well-calibrated in terms of challenge level. A number of these projects were of educational value, but were not considered successful. The case studies demonstrate that this combination is more likely to occur with industry or research-supporting projects. The complexities of "real world" projects were described in student vernacular as ambiguous, and were poorly received by students. Substantial time and effort was invested by the teams in the early project phases, resulting in a lack of traction and a perceived lack of forward progress. Coupled with high challenge level or ambitious goals, students did not react with enthusiasm and did not engage. Though these projects had early appeal due to corporate or research sponsorship, there was somewhat of a letdown if/when the projects turned out to not be well conceived or well-defined. This was somewhat of a whiplash effect and dampened students overall satisfaction with projects that experienced this condition.

Since one of the drivers of many capstone programs is to create real-world challenges, the effort to resolve F_{IIA} (Definition) and F_{IIB} (Difficulty) is very valuable in highlighting the importance of carefully monitoring projects conceived of (and defined by) individuals/organizations outside the core capstone program academic staff. Externally sponsored (non-academic) projects frequently have the greatest opportunity for engaging students and creating growth opportunities, but also pose one of the major hazards to student success.

Again, just as seen during the Type I factor reduction process, the above observation specifically delineates a programmatic and managerial responsibility of capstone program administrators: create higher challenge-level projects to push student development, but do so with enough detail to provide for early incremental successes. The FMEA methodology allows for characterizing the *types* of failures of project structure and allows for specific interventions.

Resolving Conflation in Type III Sub-Factors: F_{III} – Potential for Team Effectiveness

Recalling F_{IIIA} (Team Dynamics), F_{IIIB} (Balanced Student Experience), a similar investigation is performed on the Type III factors:

$$\underbrace{F_{IIIA} \circledast F_{IIIB}}_{Type\ III}$$

The two Type III factors that were observed as having the most impact and were a recurring theme in the case studies were Team Dynamics (F_{IIIA}) and Balanced Student Experience/EMF (F_{IIIB}). Neither one of these factors (in and of itself) is considered directly controllable, but each is clearly observable and serve as monitoring parameters for team performance. The process used for team formation (for many years) was generally to "seed" each team with several experienced students (higher Engineering Maturity Factor), and no single team was formed with uniformly low or uniformly high experience.

The original premise was that students with prior project experience in an internship or research experience would have the opportunity to apply past experiences and (hopefully) be potential leaders on their teams. Similarly, students who make an early effort to respectfully exchange thoughts and ideas were observed to have higher levels of team performance (i.e., shared vision, interdependence, trust, collaboration, communication).

These two factors combined resolve into an overall "Potential for Team Effectiveness" factor as follows:

Table 21 – Potential for Team Effectiveness

F_{IIIA} – Team Dynamics	F_{IIIB} – Student Experience Balance	F_{III} – Potential for Team Effectiveness
False	False	False
False	True	False
True	False	False
True	True	True
False –Poor Team Dynamics True –Good Team Dynamics	False – Poor/non-complimentary team balance True – Good/complimentary team balance	False – Low Potential for success True – High Potential for success

There has been considerable work done on the mechanisms of team performance in capstone. In some cases, students are permitted to self-form teams. The case studies performed as part of this effort imply that there are benefits and hazards to this method [20] . One benefit is the presumption that teams that self-form are likely to form due to friendship or mutual interest, thus giving greater likelihood of positive team dynamics. If mutual interest is also derived from mutual experiences, then teams formed in this fashion have self-aligned to the (True:True) combination and the faculty advisors are likely blind to this condition.

The home program for this work utilizes a deliberate blending of teams, acting under the presumption that one educational goal of capstone is preparing students to work with individuals with diverse skillsets and experiences (and personalities). Inasmuch as newly-graduated engineers will not have the opportunity to “pick” their coworkers (teammates), the capstone design program is considered the last educational opportunity to facilitate positive collaboration skills. While allowing self-selection of teams may be administratively simpler, one alternate view is that to do such is to abdicate the responsibility to give students a real-world team experience in a controlled setting.

The case studies evidenced that teams that exhibit the (True:True) combination, teams with positive team dynamics and a complimentary experience base, demonstrate a propensity to mutually-reinforce (effectively). These teams were generally seen to effectively collaborate, but also delegate responsibility (and tasks) with reliable results and personal accountability.

Conversely, teams with poor team dynamics and non-complimentary experiences (False:False combination) are likely to be one of the lowest probabilities for success for any combination of factors and illustrates the most important observation of this Type III resolution effort. That is, these teams may require an active faculty advising effort.

Teams with poor team dynamics but complementary experience (False:True) have been seen to go through the motions of interaction, but were also seen to lack enthusiasm and motivation. In at least one case study with positive team dynamics but non-complementary experience (True:False), the project was a technical success yet several students were relegated to peripheral tasks of minor importance. Reliance on technical measures of project success (good prototype, good report) did not adequately illuminate this phenomenon. Student reflective memoranda indicated that “social domineering” behavior occurred and several students with a good work ethic, but incompatible skills were marginalized. This result was not deemed to be an educational success.

Lastly, teams that exhibit good team dynamics but non-complimentary experiences (True:False combination) might be represented by a stereotypical young engineering team with good team dynamics/communication and divergent experience. At least one team of this type maintained a positive approach and grew together in skill-development. One caveat to this combination is that this type of team can be particularly sensitive to frustration in the early project phases and benefits from well-defined projects.

The case studies have illustrated that team dynamics benefit from good early exchanges, are positively influenced by early project success, and are time varying and quite sensitive. The case studies also revealed that sensitivity to adverse team dynamics is an advisor skill that does not always correlate with experience, but can be developed. The case studies also revealed a need for substantial development and training in this area across the entire advising cadre.

Resolving Conflation in Type I/II Interaction: $F_{I/II}$ – Creating a Positive Learning Environment

Recalling $F_{I/IIA}$ (Faculty Context-Project), $F_{I/IIB}$ (Faculty Context-Teamwork), a similar investigation is performed on the Type III factors:

$$\underbrace{F_{I/IIA} \circledast \ F_{I/IIB}}_{Type\ I/II}$$

Prior to populating the project with students and their subsequent commencement of project activities, the hope would be that project scope (difficulty and clarity) are reasonably well-defined. Past history shows that it can be difficult to craft a project description that is clear and well enough scoped to be universally digested by any project team of any composition. Further, if the project has external stakeholders or sponsors, their needs can be challenging to delineate and can be amorphous. One role of the faculty in the capstone process is to serve as the interface for the team in order to help them digest the project, as well as mediating the scope to prevent externally (and internally) driven scope creep. Faculty with student-focused teaching styles in the ETBS arena may be more focused on student perceptions and student needs and may perform well in this task ($F_{I/IIA}$).

Faculty advisors who are also sensitive to teamwork and team dynamics can foster positive internal team collaboration and positive behaviors (and largely prevent or ameliorate negative behaviors). Faculty members who are strongly student-focused in the ETBS arena also have been seen to be in tune with student sentiment and the overall learning environment of the team. One good representation of this is a faculty advisor who is rarely (if ever) surprised by what they read on an end-of-project peer evaluation. This is representative of the type of interaction seen in $F_{I/IIB}$.

When a faculty mentor can manage the project definition to properly challenge students ($F_{I/IIA}$) as well as being sensitive to the team dynamics ($F_{I/IIB}$), the faculty member has the opportunity to create a positive learning environment:

Table 22 – Facilitating Positive Learning Environments

$F_{I/IIA}$ – Faculty-Context-Project	$F_{I/IIB}$ – Faculty-Context-Teamwork	$F_{I/II}$ – Positive Learning Environment
False	False	False
False	True	False
True	False	False
True	True	True
False –does not manage scope True –does manage scope	False – Does not facilitate teamwork True – Does facilitate teamwork	False – Not a positive learning environment True – Positive learning environment

In the case of teams where faculty advisors do not facilitate the project definition or the teamwork (False:False), industry-sponsored or research-sponsored projects are susceptible to ambiguity and scope creep, as well as possible team degradation under stress. At least one of the case studies in this work contained a situation where the faculty advisor did not continuously monitor the project scope. This team had reasonable team dynamics, but since the project was industry-sponsored it suffered from early ambiguity and dramatic late-stage scope creep. This team was continuously on edge and confused about project direction (due to scope change). This caused internal stress that adversely affected internal team dynamics. Nevertheless, this project was an example of (False:True), a hands-off approach to the technical content of the project but sensitivity to the team's dynamics.

In the case of (True:False), where the faculty advising the project team facilitate project scope, but do not facilitate teamwork or demonstrate an awareness of internal dynamics, whether or not the project is ultimately successful is somewhat random, depending on the personalities of the students populating the project. Although unintended, this scenario did occur in one project cluster. One faculty advisor was assigned multiple teams working on the same project scope. The multiplicity of the project teams created a substantial opportunity for the faculty advisor, leading to an extremely well-defined project scope for all teams. Unfortunately, this capstone-experienced faculty member was also extremely heavily loaded with multiple assignments and suffered from bandwidth (F_{IB}) issues. Consequently, the multiple teams were largely left to work out interpersonal conflict and team challenges on their own. Teams that naturally demonstrated positive team behaviors were observed to have a more technically complete and more cohesive project than those teams with interpersonal challenges. This project cluster is a good representation of (True:False), where the faculty mediates the project context, but not the teamwork context component.

The case of (True:True) in this interaction is fairly apparent, but consists of a faculty advisor who can actively and continuously manage scope based on the needs of the individual project team, as well as helping facilitate healthy and constructive interpersonal interactions. In industry, this combination would be a good skillset for an engineering project lead or engineering manager.

A Simplified Model

The original representation contained seven discrete sub-factors and four interactions between the major factors:

$$P_{Success} = f(\underbrace{F_{IA} \circledast F_{IB}}_{Type\ I}, \underbrace{F_{IIA} \circledast F_{IIB} \circledast F_{IIC}}_{Type\ II}, \underbrace{F_{IIIA} \circledast F_{IIIB}}_{Type\ III}, \underbrace{F_{I/II\ A} \circledast F_{I/II\ B}, F_{I/III}, F_{II/III}}_{Interactions\ between\ types})$$

The conflation resolution has reduced the factor set to a simpler model and the associated factor definitions:

$$P_{Success} = f(F_I, F_{II}, F_{III}, \underbrace{F_{I/II}, F_{I/III}, F_{II/III}}_{Interactions\ between\ types})$$

Table 23 – Factors in the Simplified Model

	Factor	*Factor & Interaction Type*
F_I	*Quality of Faculty Engagement*	*Major Factor, Type I*
F_{II}	*Project Set-up & Structure*	*Major Factor, Type II*
F_{III}	*Potential for Team Effectiveness*	*Major Factor, Type III*
$F_{I/II}$	*Faculty-Context (Faculty facilitates positive learning environment)*	*Interaction, Type I/II*
$F_{I/III}$	*Faculty-Student (Faculty advisor engages and emphasizes student learning)*	*Interaction, Type I/III*
$F_{II/III}$	*Student-Project Alignment (Students are prepared and engaged with the project content)*	*Interaction, Type II/III*

CHAPTER VI. PRACTICAL IMPLICATIONS OF THE THEORETICAL MODEL

This work set out to take advantage of the natural-environment of the experiences of undergraduate engineering capstone students with the specific objective to identify and understand success factors and their interactions. A mixed methods approach was used, operating under the premise that a combination of qualitative and quantitative parameters would be well-complemented by a case-study analysis of a candidate set of teams. This approach was chosen to benefit from immersion in the words and experiences of the students, as well as their responses to their environment and faculty mentorship. By listening to the "voice of the student" and aligning their experiences to the nature of the project, faculty advisor, and university/community support system, relationships of factors and interactions which contributed to student educational growth and professional development, as well as project success, were observed and characterized.

This work utilizes the experiences of a student population at a large public metropolitan university for immersive study. However, the research was conducted with the intent of offering benefit to programs of all types, acknowledging the diversity of programmatic and educational structures across the nation. It can be argued that fundamentally, the theoretical foundations derived from the case study analyses are generally applicable to most any capstone project, since all programs involve capstone projects with student teams in a culminating experience under the guidance and direction of a faculty advisor. This means that the model has some rather profound and potentially far-reaching “practical implications”. The implications are that any capstone faculty advisor could use the factors and interactions identified in the theoretical model as a checklist to influence and support student success.

The pattern of major factors which was observed to influence student and project outcomes included aspects derived from student influences, faculty mentorship, and contextual/environmental sources. The factors also included a number of situations where factors from one source interacted with factors derived from another source. Chapter V integrates the observations as a theoretical model for capstone project success. The theoretical model contains eleven factors and interactions identified during the study. There is a complex interweaving between the factors, so an effort was made to simplify the model for general consumption. The effort of simplifying or reducing the model also provided an additional opportunity for presenting a detailed discussion of the nuanced complexity of relationships within the major factors and their interactions.

The results of this study were formulated into the theoretical model, and the model is offered to the capstone educational community as a tool for self-study. The value in the model lies in the establishment of a comprehensive and integrated structure for student/project success and the discourse which can be stimulated by evaluation of the practical implications of the model for programs of varying kinds. In keeping with this train of thought, the following sections present the impact and implications from the theoretical model on practical application.

Practical Implications of Faculty Advisor Sub-Factors (Type I)

From the full model, the sub-factors within the Type I area were F_{IA} (Faculty Advisor Experience) and F_{IB} (Faculty Advisor Bandwidth). Both sub-factors speak to the Quality of Faculty Engagement, identified as F_I in the model reduction exercise. It was observed that faculty advisors of sufficient experience were well calibrated and capable of providing guidance to capstone project teams based on their understanding of student needs and motivations. From a practical standpoint, this implies the converse is also true; that is, that faculty advisors with insufficient experience were perhaps unable to anticipate student needs. Capstone program coordinators, as well as department chairs would benefit from this information, specifically to note that new faculty members, junior industry engineers and graduate students may not make ideal faculty advisors for these types of projects. Individuals asked to support capstone activities that are relatively new to professional practice (either in academia or industry) would themselves likely benefit from a formal introduction to capstone education and/or perhaps taking the form of co-advising for some period of time.

Faculty members in the university environment typically have teaching responsibilities layered on top of research responsibilities. Similarly, adjunct faculty from industry have teaching responsibilities layered on top of full-time industry responsibilities. While it may be common to discuss research work-load or teaching-workload within the educational community, it may be less common for individuals to discuss their own capacity for technical and professional engagement as capstone project advisors. Capstone coordinators must consider the workload of potential capstone project advisors, as well as other time commitments (e.g., family, community, health, etc.). There were several instances observed where otherwise excellent faculty advisors were unaware or out of touch with project teams simply due to their workload and other commitments.

Quality of Faculty Engagement (F_l) largely consists of recruiting appropriately qualified individuals, training them for particular skills required of capstone faculty advisors, and monitoring their overall capacity to ensure that students get the benefit of their experience and expertise. The requirement to do these three simple things provide potential opportunities for significant improvement in capstone student success and satisfaction.

Practical Implications of Contextual Sub-Factors (Type II)

From the full model, the sub-factors within the Type II area were F_{IIA} (Project Definition), F_{IIB} (Project Challenge Level), and F_{IIC} (Resource/Support Level). During the reduction exercise for the simplified model, these were simplified to Project Set-Up and Structure, Factor F_{II}.
The size and scope of a large university capstone program provides many challenges, among which is the need to provide fulfilling projects to meet student needs. Project sourcing from industry, faculty, and students requires a vetting process where projects must “pass muster” for adequacy, prior to engaging student teams. In light of the observations from this research, it is clear that although a capstone project is intended as an “open-ended” culminating experience, it is also clear that project set-up is a critical parameter ultimately affecting team dynamics and individual student outcomes.

As a result of this research and the observations from the case studies, the following questions for consideration are recommended during the project vetting process:

- Do the faculty understand the project sufficiently to provide guidance?
- Does the project definition contain enough information about stakeholder (sponsor/faculty/student) intentions to believe it is a viable project?
- Would an entry-level engineer understand what is being proposed?

- Are the skills required for the project either already within the curriculum or achievable via self-study in a reasonable timeframe?
- Does the project have clear goals and objectives?
- Can the project be structured with incremental milestones and deliverables so that students can navigate the project?

One important aspect of the project definition assessment in this work was the observation that student project teams are particularly sensitive to early progress and quickly become frustrated with any perceived lack of progress. It was observed that teams that make early progress on their projects tend to be more positive and engaged towards the end of the project. This speaks to a concern that the early-project structure and final deliverables should be scoped in order to build confidence in project teams.

The research has also illuminated that the vetting process allowed potential projects to succeed even though they may have been poorly defined in terms of Challenge Level (F_{IIB}). Various projects were posed to students that either did not sufficiently challenge students or were too challenging. The primary source of concern, especially in the latter scenario is that expectations of students must be properly calibrated to student capabilities. Practical implications for consideration of capstone project challenge level include:

- Has the project sponsor/stakeholder evaluated the program curriculum to calibrate their expectations?

- What specific technical, software, or analytical skills will be required for the project and at what skill level?
- Has the time commitment required for each deliverable been assessed or quantified?
- Has the schedule required for each deliverable been assessed or quantified?

The third Type II sub factor, F_{IIC} (Resource/Support Level) is also comingled with the issue of lack of project definition, which is a reason why the sub-factors were reduced to a single factor F_{II}. Projects from industry or faculty that were perceived to be "real world" challenges ideal for students were allowed to proceed, only to determine in late-stage project development that these projects required unforeseen laboratory space, manufacturing/prototyping space, machining or manufacturing support, or simply an extensive budget for components. Students have been observed to spend valuable educational time scrambling for budgetary or logistical resources. While these may be "real-world" challenges, this is a relatively poor use of time and effort, resulting in unproductive delays, inadequate development, and team frustration. While effort to precisely quantify the impact on educational development and project outcomes may be a potential area for future work, it was observed that several of the case study teams likely lost several weeks of productive time scrambling for additional resources that could have been identified prior to project initiation. Questions to ask as part of the screening criteria include:

- What are physical space requirements for the project and how will space be allocated?

- What budget will the team require for the project, and where will this budget come from? Are there reserves for contingencies?
- Will the team require manufacturing and/or testing support? This might include machine shops, 3D printing, electronics resources, software, etc. Several cases studied in this research effort experienced issues with CNC machining support and advanced manufacturing support (3D Printing, laser cutting). Contemporaneous issues outside the teams/cases studied also included access to wind tunnels, computational support, etc.

The case studies revealed that robust screening efforts are required to identify deficiencies in project definition, challenge level, and resource requirements. Simply asking the right questions as delineated above, in the form of a checklist would go a long way to mitigate project risks. Indeed, many of these questions (if asked at the proper time) would be questions appropriately posed to external project sponsors or faculty/research sponsors. Resolving these issues mid-project requires project re-scoping and the potential for student and stakeholder dissatisfaction, and failure to deliver on project objectives.

Practical Implications of Student Influence Sub-Factors (Type III)

From the full model, the sub-factors within the Type III area were F_{IIIA} (Team Dynamics) and F_{IIIB} (Student Experience Balance), which converged into F_{III} (Potential for Team Effectiveness) in the simplified model. The focus was to observe existing conditions and attempt to ascertain their influence in overall student success, rather than emphasize management of teamwork and team dynamics. As previously stated, the method utilized for team formation in the capstone program under study is an instructor-assigned team composition. This procedure is utilized in the interest of creating a balance of team skills and experience aligned with student interests and project requirements. It is also in keeping with the notion that upon graduation, engineering students will generally be hired by companies and not have the luxury of selecting their co-workers. By forming teams in this way, the program drives students to develop interpersonal skills in communication, collaboration, and organizational interdependency that might not otherwise be challenged for self-selected teams [20] .

The case study analyses show that the optimal combination of Type III factors which lead to higher “Potential For Team Effectiveness” come from teams with positive team dynamics as well as a complimentary balance of student experience. The practice of creating complimentary teams by “seeding” teams with students with prior experience (co-op, internship, etc.) then fleshing out the team with students of compatible skills appears to provide value. What is unpredictable is the initial team dynamics. During team formation and early-stage project development, it was observed that actively structuring course/project deliverables that are designed to positively reinforce teamwork and cohesiveness adds value. Additional leadership and personal development skills training may also benefit student teams. Students in this study were all given the opportunity to participate in an engineering leadership experience (a capstone design “boot camp”). Teams that internalized the content were observed to be more cohesive and productive.

From a practical application standpoint, questions for consideration by capstone program coordinators and faculty advisors include:

- Are my teams balanced with complimentary technical knowledge and skills?
- Do the teams have the appropriate experience mix required for the project to which they are assigned?
- How familiar are faculty advisors with their students? Do they know their names, have their resumes and know their past experiences?
- Are faculty advisors calibrated to which students might fit various team roles and responsibilities?
- Do students have reasonable goals of what they hope to accomplish based on their backgrounds and experience? Are faculty advisors discussing these goals with them?
- Do students have good communication skills? Can they give and receive constructive feedback? Do they know what it means to be accountable to peers?

- Do faculty advisors understand the fundamentals of teamwork and the impact of team dynamics? Do the faculty advisors have strong communication skills?
- Do students feel comfortable communicating their team challenges to their faculty advisor?
- Is the faculty advisor getting accurate and timely peer evaluations?
- Is the faculty advisor aware of what individual students are doing and accurately assessing the division of labor on the team?
- Are students actively engaging with each other, or are they compartmentalized?
- Are there any social loafers in the group, or are there any socially domineering team members?

Practical Implications of Faculty-Context Interactions (Type I/Type II Interactions)

From the full model, the sub-factors within the Type I/II interaction consist of $F_{I/IIA}$ (Faculty/Context - Project) and $F_{I/IIB}$ (Faculty/Context - Teamwork). The $F_{I/IIA}$ (Faculty/Context – Project) interaction acknowledges that an important role of the faculty advisor is to remain calibrated to whether students are appropriately challenged at all phases of the project. While early administrative efforts to screen and define projects may establish that a project is appropriate for inclusion in the course project offerings, larger programs may delegate subsequent oversight to supporting faculty, who then must bear the oversight responsibility until project completion. Results from the case studies in this research show that effective faculty advisors are sensitive to the efforts of the students and can provide incremental (and continuous) goal-setting on an individual student, as well as team basis. Faculty advisors who are sensitive to scope creep imposed by external stakeholders or students themselves, can help them maintain a healthy and achievable challenge level.

The second interaction sub-factor, $F_{I/IIB}$ (Faculty/Context – Teamwork) deals with whether the faculty advisor is sensitive to the interactions and emotional sentiment of the team. When teams are suffering impending dysfunction, the most effective faculty advisors are sensitive and can stage interventions and mediate team attitudes back towards healthy and productive behaviors. This type of coaching can be perceived as a leadership function on the part of the faculty advisor and requires sensitivity to moods and attitudes of students.

Practical questions for these two scenarios include:

- Is the program/department hiring faculty advisors with a past history of effective management practices and supervisory experience?
- Are faculty advisors modifying scope or clarifying deliverables so that students have a manageable and appropriately challenging project?
- Do faculty advisors push for additional performance from teams who find the project easy and push back against scope creep?
- Are faculty advisors sensitive to the nuances of interpersonal relationships of the individuals on their own teams or teams they have supervised?
- Can faculty advisors themselves give constructive criticism and coach others to do the same?
- Are faculty advisors ever surprised by student peer evaluations?

The ideal faculty advisor is someone who:

- Helps the team develop a shared understanding of project goals and objectives.
- Takes a program-defined project and maintains/modifies scope with appropriate programmatic consultation.

- Knows a team’s stress and work levels, and appropriately challenges each individual on the team.
- Knows each team member’s mood towards the project and their peers, and intervenes/counsels if required.
- Coaches senior level engineering students and develops their communication skills
- Instills a sense of accountability, trust and professionalism in all team members.

Practical Implications of Faculty-Student Interaction (Type I/Type III Interactions)

This factor ($F_{I/III}$) is the first of only two factors that was not included in the model conflated or interacting with any other factor. It is simple in principle, but somewhat more difficult to assess. The research specifically assessed this interaction with the ETBS and how teacher beliefs resonated with students' perception of the quality of instruction. As opposed to larger discipline-specific core curriculum courses that are traditionally lecture based, the more intimate relationship between a capstone project team and a faculty advisor imparts a required sensitivity towards students as individuals. That is, faculty members with their primary teaching experience in lecture-based courses may require development to become more "student-focused" versus "teacher-focused". The most effective capstone mentors are sensitive to the student individual and team needs, and likely have a strong history of positive student feedback.

Practical considerations for this factor for programs applying the theoretical model of capstone success might include:

- Does the faculty advisor appreciate the need to maintain student motivation, and do they know what drives each student to succeed in their academic work and the project?

- Are students responding to the faculty advisor's guidance with acceptance or reluctance?
- Is the faculty advisor conveying the need for guidance in such a way that students are motivated?
- Can the advisor provide appropriate technical advice in the area of the design project? Do they understand engineering design methodology and can they provide guidance?
- Is the faculty advisor proactive in responding to student needs such as assistance in project management, meeting facilitation/organization, stakeholder relationships?
- Do students see the faculty advisor as someone worthy of respect as an individual, rather than based on their position?

Practical Implications of Context-Student Interaction (Type II/Type III Interactions)

Context-Student Interaction ($F_{II/III}$) is the second of the two factors from the model without conflated or interacting factors and thus appears in both the full and reduced theoretical models. From a practical standpoint, the most apparent representation of this factor is how students (as individuals and as teams) interact with their project context and their team environment:

- Do students have the appropriate skills for the project, or can/will they develop them?
- Of a more sensitive nature, are students mature enough for the project? Are the students capable of representing the university in a professional fashion? Do they take intellectual property considerations seriously?
- Do students identify with the project? Is it something that they chose? Is it something that motivates them?
- Do students respect the role that their teammates have in project success? Are the students willing to create a healthy project environment by contributing, showing respect for peers, etc.?

Since student proclivities are essentially a truly uncontrollable factor, the primary practical considerations of this factor include:

- Crafting a sufficiently diverse pool of projects so that all students can be placed on projects that motivate them.
- Matching students with projects that take advantage of their existing skills and challenge them appropriately to develop new skills.
- Creating a course and program culture that establishes an expectation of collective engagement and accountability.
- Creating a course and program culture that establishes an expectation of mutual respect, fostering healthy project-focused collaboration.

CHAPTER VII. SIGNIFICANT CONTRIBUTIONS, FUTURE WORK, AND CONCLUDING REMARKS

Significant Contributions

Arguably, capstone is probably the most difficult and complex course to administer and instruct in the engineering curriculum. While the capstone educational community has made great advances to improve upon successful course delivery over the past two decades since ABET 2000 introduced the culminating experience as a requirement for the engineering curriculum, capstone instructors across the nation continue to struggle with the varying levels of success seen with capstone student projects. To address this issue, this thesis presents a comprehensive in-depth understanding of the issues and success factors associated with capstone design teams, looking beyond the past work which typically has focused on single factors without consideration of the complexity associated with the various interactions.

Employing a mixed-methods approach, a research framework for assessing the factors impacting success on capstone design teams was developed (see chapter 3, Figure 2). The research framework employs the use of program-wide quantitative data, as well as an immersive case-study approach to examine the nuanced complexity of faculty, student and contextual influences. Two new survey instruments specifically customized to cater to the capstone community (i.e., CSPIS and ETBS) have been developed and implemented to simultaneously explore the perspectives of both students and faculty. Using end of semester student reflective memos coupled with course and survey data, this thesis investigates nine individual project case studies to develop an improved understanding of some of the most significant issues that impact capstone student success. This immersive approach and the subsequent organizational methodology has resulted in a novel theoretical model with practical applications for design, management, and assessment of capstone design.

Based upon the findings from the in-depth case study analyses, chapter V translates the observations into a theoretical model for capstone project success that integrates the related sub-factors within the major factors of Faculty (Type I), Context (Type II), and Students (Type III), as well as consideration of the various interactions *between* the major factors. The theoretical model contains eleven factors and interactions identified during the study. There is a complex interweaving between the factors, so an effort was made to simplify the model. The effort of simplifying or reducing the model also provided an additional opportunity for presenting a detailed discussion of the nuanced complexity of relationships within the major factors and their interactions. The results of the case study analyses formulated in the theoretical model are offered to the capstone educational community as a tool for self-study. The value in the theoretical model lies in the establishment of a comprehensive and integrated structure for student/project success and the discourse which can be stimulated by evaluation of the practical implications of the model for programs of varying kinds.

The original objective of this research was to formulate functional relationships into a practical model for operational application. In chapter VI the theoretical model is further distilled to a level appropriate for practical application. Using the theoretical model as a guide, a checklist of questions are presented. The research acknowledges the diversity of capstone programs throughout the nation (see Chapter 2, Table 1). It can be argued that fundamentally, the theoretical foundations derived from the case study analyses are generally applicable, since all programs involve capstone projects with student teams in a culminating experience under the guidance and direction of a faculty advisor. This means that the model has some rather profound and potentially far-reaching "practical implications". The implications are that any capstone faculty advisor could use the factors and interactions identified in the theoretical model as a checklist to influence and support student success.

Drawing from the practical implications and utilizing the full version of the theoretical model, the following represents a simple starting point for self-assessment of capstone programs. This simplified summary is presented for the purpose of final remarks, with a more critical and fully-formed set of questions posed in Chapter VI:

Programmatic Self-Assessment Checklist

1. Faculty Advisor Experience: Does the faculty advisor have appropriate experience?
2. Faculty Advisor Bandwidth: Will the faculty advisor be able to focus their experience to aid students?

3. Project Definition: Is the project defined well-enough for students?
4. Project Challenge Level: Is the project challenge calibrated properly for students?
5. Resource/Support Level: Are there sufficient resources available to properly support the project?
6. Team Dynamics: Are faculty aware of team dynamics during early team formation?
7. Balanced Student Experience: Are teams balanced specifically for skills and experience required for the project?
8. Faculty/Project Context: Are faculty actively managing project scope as appropriate?
9. Faculty/Teamwork Context: Are faculty aware of and managing the student team interpersonal dynamic?
10. Faculty/Student Interaction Are faculty predisposed towards and actively focused on optimizing student learning from the project?
11. Student/Project Alignment: Are the projects designed to appeal to and engage students based on the project content, student competencies, etc.?

While this simplified set of questions (and the others discussed in more detail in Chapter VI) may be provocative in terms of unearthing programmatic flaws, past observations indicate that the broader capstone community would benefit from the structured inquiry proposed herein. Any self-assessment performed in a structured fashion (rather than an ad-hoc review) can only benefit the quality of an educational program (and the students who partake of that program) and is precisely the kind of continuous improvement effort espoused by ABET.

Recommendations for Future Work

The research framework, theoretical foundations and practical implications presented in this thesis provides a starting point for future work to truly understand engineering capstone design teams. The research framework, theoretical model and check-list of questions for practical applications developed in this dissertation provides a starting point for programmatic self-assessment. Together they have the potential to assist capstone instructors in conducting a systematic series of improvements. As a research tool, a number of other opportunities have presented themselves for future work and are delineated in the following paragraphs.

Design of Experiments for Factor Analysis

A repeated theme in this work was that the model was being constructed to identify functional relationships rather than explicit, quantified relationships. Nevertheless, this research has identified eleven candidate factors (in the full model) that impact student success. A very natural extension of this line of inquiry is to attempt to make those relationships more explicit. With appropriate sample populations, possibly from one university, or possibly from more than one, it should be possible to conduct a Design of Experiments on a subset of the factors to more firmly establish the weights or relative influence on team project performance. With the proper approach, a Design of Experiments methodology would be a valuable area of exploration. Drawing from the observations and experiences of the current work, the most appealing candidates for this exploratory work are the faculty engagement, project definition (clarity), and team dynamics components.

Multi-University Application of the Model

The research framework and theoretical model presented in this dissertation is drawn from the program structure of the program under examination. Repeated references in this work acknowledge the diversity in program structures around the nation. A broad, multi-university research effort including programs of differing disciplines, faculty-student interaction structures, and durations would be of immense value in determining how broadly the model is applicable. Aspects of the model that are viable in high-population programs may be irrelevant in smaller programs, and issues that occur in smaller programs may have been masked (and therefore not included in the model) based on the sheer size of the program from which the model was developed. Future work in this field would benefit from multi-university collaboration, as multiple perspectives and insight would be beneficial in guiding such an investigation.

Engineering Teacher Beliefs and Capstone Student Perceptions of Instruction Relationships

The application of the ETBS is an extension of prior work in teacher belief impact. The nature and structure of capstone education as a subset of engineering education, however, provides a unique opportunity to apply this work in a novel way. Since capstone education is typically small-group driven and frequently requires faculty to interact more closely with students, the impact of educator beliefs on student educational development may be more pronounced than in a traditional lecture-based course. The capstone-based inquiry on student perception of instruction (CSPI) did indicate that students are perceptive and aware of high quality faculty engagement. Further inquiry into precisely how strong of a response from students such an engagement can elicit would be an excellent use of this tool and could quite likely provide additional guidance on mentor selection.

Single Factor Influences: Impact of Project Definition as a Predictor of Engineering Capstone Success

During the culminating phases of this research, a contemporaneous issue has arisen that drives use of some of the research observations before this work is published. More specifically, in the Spring term of 2020, the Covid-19 pandemic has dramatically altered the needs of capstone education. The observations presented earlier in this work regarding student response to well-structured and well-defined projects are being put into effect for 80+ students in the Summer 2020 term. This work will likely guide the project definition process for hundreds of additional students in the Fall 2020 term. More specifically, the projects for these two population groups are being defined to be clearer, with precise objectives and deliverables. The driving motivation for this change in structure is to ameliorate the impact of virtual collaboration, remote team meetings, etc. As these students conclude their capstone experience, it would be appropriate to assess their performance, as well as conduct a student-perception solicitation to determine the impact of project definition emphasis for their learning cohort(s).

Multi-factor Influences: Impact of the Interactions of Faculty, Student, and Contextual Factors

Much like the value of investigating a single factor (such as project definition), there is value in investigation of the interactions between different types of factors. Whether this is referred to as multi-type or multi-factor is a semantic nuance, but the emphasis lies on the last three factors in the simplified model (or last four from the full model). The role that faculty serve in creating a positive learning environment for capstone students, the behavioral manifestation of faculty beliefs (ETBS) in the interactions with students, and the required parameters for project composition that appeal and optimize student engagement are all strong areas for exploration.

Using Capstone Project-Level Student Perceptions of Instruction as a Real-Time Monitor for Continuous Improvement of ABET Accreditation Metrics

Student perception of instruction (in its various forms) is broadly viewed as a useful tool at the institutional level for evaluating faculty performance. Preliminary observations of several applications of this process indicate that an institutional-level survey is unlikely to ask the appropriate questions for an ongoing diagnostic self-assessment of the quality and health of a capstone program. Utilizing a capstone student perception of instruction (the CSPI) as a method of gathering the so-called "Voice of the Student" would be a powerful way of assessing the impact of a capstone program on student satisfaction. If properly paired with adequate supporting documentation (reflective memoranda, for example), the CSPI holds potential for being a program-level diagnostic tool, evaluating faculty engagement, student learning, and alignment of the student capstone experience to the ABET-recommended student learning outcomes.

Social Network Analysis of Capstone Student Peer Evaluations

In the early phases of this research work, it was desired to complement the immersive assessments of the peer evaluations of the case study teams with a broader Social Network Analysis. That effort was judged to be highly valuable in understanding the dynamics of student teams and the impact on team performance. To manage the scope of the research work, a decision was made to emphasize the case study approach and restrict the study of the peer evaluations to the teams under review. Nevertheless, the peer evaluation data is available for a very large population set (spanning multiple semesters/years). From a big-data approach, mapping student peer evaluations from a Social Network Analysis perspective and mapping those results against overall team performance has promise in helping understand the relationship between team-dynamics and overall team success. From a social science and engineering team performance perspective, the results of such a study would be of value in team formation, team management, and overall program administration.

Concluding Remarks

Engineering capstone design is intended to be an integrative experience for students to practice knowledge and skills learned during earlier stages in the engineering curriculum. Capstone projects act as the ultimate test for students who are close to graduation and are intended to build confidence and prepare engineering graduates to "hit the ground running" upon entry into the workforce. While the primary focus of this thesis has been on the capstone course and program itself, the broader implications of the culminating experience on the entire engineering curriculum deserve mention. In essence, capstone is much more than a course. Capstone is a window on the curriculum and offers huge opportunities for continuous improvement to prepare students for their careers as engineers.

Beyond the basic student outcomes delineated by ABET, our students are far more capable than we may notice. With appropriate guidance and support, our students can be amazing! Imagine students who can truly apply creativity, critical thinking, initiative and analytical skills toward solving the many challenging problems in the world. Indeed, the engineering design process taught in capstone is the problem solving methodology that could and should be taught in the first year and throughout the curriculum. Implicit in the engineering design process is the need for teamwork, communication and many of the advanced technical skills we all want to see our students develop. To the extent that this thesis has provided an improved understanding of student success factors, perhaps this newfound knowledge can be used as a step toward broader curriculum reform.

APPENDIX A: ENGINEERING TEACHER BELIEF SURVEY (ETBS)

Traditional Teacher Focused

1. I view my role as an educator as a technical expert who delivers engineering knowledge content.
2. My students learn engineering best by taking good notes and paying careful attention to me during design meetings.
3. Careful planning by the faculty advisor and well prepared agendas maximize student learning.
4. Students develop an understanding of the content based upon information delivered to them in design sessions.
5. The syllabus provides guidance on what to teach students for their specific design project.
6. I encourage students to move on to new phases of their design project after they have expended the time allotted by the course schedule.
7. When students are paying close attention to me during design sessions I know that learning is occurring.

Instructive Teacher Focused

1. As an engineering educator, my job is to motivate student interest to learn technical content.

2. My students best learn engineering by integrating technical content from prior coursework into their projects.
3. As an engineering educator, I maximize learning and comprehension by carefully observing student responses during design sessions.
4. I know students understand when they are correctly applying technical solutions to their project.
5. I know what guidance or instruction to provide based on what students need for their professional practice.
6. I encourage students to move on to the next phase of the design process when they understand the design principles for the current phase.
7. I know that learning is occurring based on critical assessment of design deliverables (reports, presentations, etc.)

Transitional

1. My role as an educator is to serve as a guide for developing understanding of engineering principles and practice.
2. Students best learn engineering with hands-on laboratory/prototyping activities.
3. To maximize student learning I build a positive supportive environment.
4. I know students understand when they can describe what they have learned.
5. I decide what to teach or what not to teach based upon student feedback.

6. I move on to a new topic in when students are able to use the design process to solve problems.
7. I know when learning is occurring when the students are actively engaged.

Responsive Student Focused

1. My role as an engineering educator is as a facilitator who sets up the project for students to engage in inquiry and exploration.
2. Students best learn engineering when they interact with each other as they explain their results.
3. To maximize project-based learning I use design sessions to encourage students to share ideas, predict results and ask questions.
4. I know students understand when they can use the knowledge gained to solve a practical problem
5. I manipulate project scoping based upon the interests and capability of students.
6. I encourage students to move forward onto new project phases when students are comfortable with the content.
7. I know learning is occurring for the project team when the students interact and work together to solve problems.

Reform-based Student Focused

1. My role as an engineering educator is as an advisor and mentor who helps students reconcile what they know and what they can learn.
2. Students best learn engineering when they take ownership of what they have learned.
3. I maximize student learning by allowing students to choose their own methods for learning.
4. I know students understand when they can apply fundamental engineering concepts to expand their knowledge in new areas.
5. I decide what to encourage students to develop for their projects based upon what is cognitively appropriate for students and aligned with accepted standards.
6. I encourage students to move on to new topics when they are applying the concepts to new situations and asking questions about the concepts.
7. I know when learning is occurring when students formulate thoughtful questions about the project.

APPENDIX B: END OF SEMESTER REFLECTIVE MEMO ASSIGNMENT

Final Semester Memo and Peer Evaluation

Write a final semester memo to your faculty advisor that summarizes your accomplishments during the semester, and review of your design process. Consider this to be your opportunity to provide direct input to your individual performance appraisal. You should include in your memo a brief statement of the original project objectives. You should answer the following questions:

Motivation: How motivated were you to work on the project? Were you really excited, moderately interested or somewhat apathetic? What influenced your motivation level? How did things change as the semester progressed? If you were not highly motivated, did you do anything to change this?

Technical Contributions: Describe the nature of the technical problem(s) you solved. How did you approach the problems? What were the results?

Project Management Contributions: Did you play a special role? What kinds of significant project management contributions did you make toward achieving project goals?

Learning: What do you think you learned? What kinds of challenges did you face? Was the challenge level too high, just about right, or too low? Did you have to teach yourself anything new beyond your course work? If so, do you think it was fair that you needed to do so? Explain. What is your assessment of your individual performance?

Design Process Improvement: Review your design process and list two or three things in the following areas:

- Successes: Things you plan to use (do) in your next design project again
- Failures: Things that did not work, and plan to do differently in your next design project
- New Ideas: Things you plan and/or want to try in your next design project

Your final semester memo should be 1 to 2 pages (single spaced 12-point font).

In addition, you must prepare a peer evaluation for everyone on your team, including yourself. The peer evaluation consists 14 questions (see attached rubric).

Please use the following grading system for section two, item 13 Letter Grade: A: 4, A-: 3.75, B+: 3.25, B: 3, B-: 2.75, C+: 2.25, C: 2, C-: 1.75, D+: 1.25, D: 1, D-: 0.75, F: 0

Note: Your reflective memo and peer evaluation will remain confidential between you and your instructor (i.e., your project advisor) and will not be shared with anyone else associated with the project.

APPENDIX C: STUDENT PEER EVALUATION QUESTIONNAIRE

Section 1	Evaluation Criteria	Score				
		0.2 (Poor)	0.4	0.6	0.8	1.0 (Good)
1	Attending Meetings - Dependability & Commitment	Missed most meetings	Made few meetings	Made some meetings	Made most meetings	Made all meetings
2	Attending Meetings - Preparedness	Arrived late, was a drain on the team, left early	Sometimes on time, sometimes ready to work	Mostly on time, mostly ready to work	Usually on time, usually ready to work	Arrived early, ready to work
3	Attitude - Openness	Criticized with no solution offered, treated others unprofessionally	Sometimes open to ideas, and sometimes treated others with respect	Mostly open to ideas and mostly treated others with respect	Usually open to ideas and usually treated others with respect	Open to ideas & treated others with respect
4	Attitude - Positive	Rarely demonstrated a positive working attitude	Sometimes demonstrated a positive working attitude	Mostly demonstrated a positive working attitude	Usually demonstrated a positive working attitude	Always demonstrated a positive working attitude
5	Support Team Goals -	Poorly organized	Sometimes organized	Mostly organized	Usually organized	Always organized
6	Support Team Goals - Dependability	Rarely met deadlines	Sometimes met deadlines	Mostly met deadlines	Usually met deadlines	Met all deadlines
7	Support Team Goals - Taking responsibility & productivity	Rarely accepted responsibility, shared many ideas, made fair or outstanding contribution, and helped others with their work when needed. responsibility, shared many ideas, made fair or outstanding contribution, and helped others with their work when need	Sometimes accepted responsibility, shared many ideas, made fair or outstanding contribution, and helped others with their work when needed. responsibility, shared many ideas, made fair or outstanding contribution, and helped others with their work when n	Mostly accepted responsibility, shared many ideas, made fair or outstanding contribution, and helped others with their work when needed. responsibility, shared many ideas, made fair or outstanding contribution, and helped others with their work when need	Usually accepted responsibility, shared many ideas, made fair or outstanding contribution, and helped others with their work when needed. responsibility, shared many ideas, made fair or outstanding contribution, and helped others with their work when nee	Always accepted responsibility, shared many ideas, made fair or outstanding contribution, and helped others with their work when needed.
8	Support Team Goals - Focused	Rarely worked on project related tasks during meetings rather than Facebook or homework for other classes.	Sometimes worked on project related tasks during meetings rather than Facebook or homework for other classes.	Mostly worked on project related tasks during meetings rather than Facebook or homework for other classes.	Usually worked on project related tasks during meetings rather than Facebook or homework for other classes.	Always worked on project related tasks during meetings rather than Facebook or homework for other classes.
9	Support Team Goals - Teamwork	Rarely worked well with others	Sometimes worked well with others	Mostly worked well with others	Usually worked well with others	Always worked well with others

APPENDIX D: POST HOC IRB EXEMPTION MEMORANDUM

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138, IRB00012110
Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

Memorandum

To: Kurt Stresau

From: UCF Institutional Review Board (IRB)

Date: July 13, 2020

Re: Request for IRB Determination

The IRB reviewed the information related to your dissertation: *A MIXED METHODS ANALYSIS OF FACTORS INFLUENCING SUCCESS AND FAILURE IN UNDERGRADUATE ENGINEERING CAPSTONE DESIGN EXPERIENCES*

As you know, the IRB cannot provide an official determination letter for your research because it was not submitted into our electronic submission system.

However, if you had completed a Huron submission, the IRB could make one of the following research determinations: "Not Human Subjects Research," "Exempt," "Expedited" or "Full Board".

Based on the information you provided, this study would have been issued an Exempt Category 1, 2(ii) and 4(ii) determination outcome letter had a request for a formal determination been submitted to the UCF IRB through Huron IRB system.

If you have any questions, please contact the UCF IRB irb@ucf.edu.

Sincerely,

Renea Carver
IRB Manager

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