AC 2009-1509: A FRAMEWORK FOR ASSESSING THE INFLUENCE OF VARIATIONS BETWEEN INDIVIDUAL CAPSTONE EXPERIENCES

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A Framework for Assessing the Influence of Variations between Individual Capstone Experiences

Abstract

Within the boundaries of a single capstone course, the experiences of different students can vary greatly. Different students tackle different problems, work with different clients, are advised by different faculty and are organized into unique teams. Such a range of experiences within a single course is not typical; many courses are designed with the opposing goal of providing as uniform of an experience as possible to all students. Due to this fundamental difference, that some courses aim to provide a uniform experience for all students while others embrace a range of experiences for individual students, the same evaluation framework cannot be applied to both types of courses.

While an evaluation framework for a course with minimal variation between student experiences can assume that each student receives the same "treatment," the effect of differences between individual student experiences must be integrated into an evaluation framework for a capstone course within which there is a large range of individual experiences. In this paper, an assessment framework is introduced which assesses the effect that differences between capstone experiences have on student outcomes.

The proposed framework identifies sources of variation in a student's capstone experience that are endogenous to the course (e.g., project type, team size) and exogenous to it (e.g., students' prior knowledge, students' demographics). This approach emphasizes an understanding of the underlying aspects of each student's individual capstone experience. In addition, differences that students bring with them to capstone, including prior industrial experience, academic performance, and demographic differences, are integrated into the framework. Understanding the connection between these differences and the fulfillment of desired outcomes is important to informing the structure of a capstone program.

Through a detailed case study with Systems & Information Engineering capstone students at the University of *East*, it is established that variation between individual student capstone experiences influences student outcomes. Variation in gender, previous work experience and differences in the level of interaction with clients all influence the achievement of several measured objectives. The assessment framework reveals the connections between specific independent variables and outcomes. Strengths and weaknesses of the framework are discussed and opportunities for future work will be explored.

Motivation for the Framework

In response to critiques that engineering graduates lacked practical design skills relevant to industry, capstone design courses have become, during the last two decades, a standard component in the final year of most undergraduate engineering curricula[3, 2]. While each capstone course is unique, most include teams of students under the direction of a project advisor working on a real (or at least "realistic") design project[5]. Teams typically submit written and oral deliverables and may also implement and test an actual design. Process-focused capstone courses can provide a stark contrast to many outcome-focused engineering courses earlier in a curriculum in which the focus is more heavily weighted towards theoretical analysis tools.

Another way in which capstone courses are different than engineering analysis courses is the variability between the experiences of individual students within a course. In an effort to provide a fair course for all students, many engineering analysis courses are designed to provide a unified experience to all students. All students attend the same classroom experiences (e.g., lectures), use the same textbook, have the same instructor, complete the same assignments, and take the same tests. While there are clearly examples where such a unified experience does not exist -- for example, multi-section courses with different instructors -- many of these exceptions are the result of practical logistics (e.g., classroom size) and faculty frequently strive to minimize the differences through using the same text, assigning similar homework, and using common examinations across multiple sections. A singular experience for all students makes sense from a workload perspective, too: a unique experience for each student would seem to require more time and energy from an instructor. This is not to say that a course designed to provide a uniform student experience does not treat each learner as a unique person with unique learning styles and pre-existing knowledge structures. To the contrary, “uniform experience courses” can be designed to be “robust to” differences among students. As engineers are known for designing systems to be robust to differences between individual users and other "noise" factors, it would be only fitting that engineers would design courses to be robust to differences between individual students.

Whereas the aim in many outcome-focused engineering analysis courses is to minimize the variability between the experiences of individual students, such variability is frequently integrated into process-oriented capstone courses. Students work on different teams, each working on different projects or different parts of the same larger project. A single person does not always advise all of the capstone teams and deliverables for each team may not be the same. Even when deliverables are identical between teams, expectations for those deliverables among the different project advisors can vary. Some teams may have industrial clients, others may be working on “design contest” projects (e.g., SAE Mini-Baja, Solar Car), others may be working for faculty as part of the faculty member's research, while others may be working on projects of their own creation. Students may be working on teams composed of students from several majors or they may be working on teams with students only from their own major. The variability between individual capstone experiences is rooted, at least in part, in necessity. For large programs, it is simply impossible to provide a realistic design experience that is uniform for all students. The variability, however, can also be designed into a program purposefully. Such purposeful variability can allow students to pursue an experience that best meets their needs. Which project topics, project advisors, client types, etc., would help the student meet their objective most effectively?

This fundamental difference, that some courses aim to provide a uniform experience for all students while others embrace a range of experiences for individual students, motivates the work presented in this paper. Whereas an evaluation framework for a "uniform experience course" can assume that each student receives the same "treatment," the effect of differences between individual student experiences must be integrated into an evaluation framework for a "unique experience" course. In this paper, we present a "unique experience" course evaluation framework in the context of capstone course evaluation, outline three macro-level case studies to show the flexibility of the framework, and present one detailed case to demonstrate the framework more fully.

An Evaluation Framework for Capstone Courses

The objective of the Capstone Variability Framework (CVF) is to acknowledge and evaluate the effects of variations within a capstone course. The CVF is not a tool for evaluating the performance of individual students. The intent of the framework is to provide a method to evaluate the unique individual capstone experiences within a single capstone course.

As shown in Figure 1, the CVF is founded in the familiar approach of studying the impact of various factors on responses that measure the performance of a system.

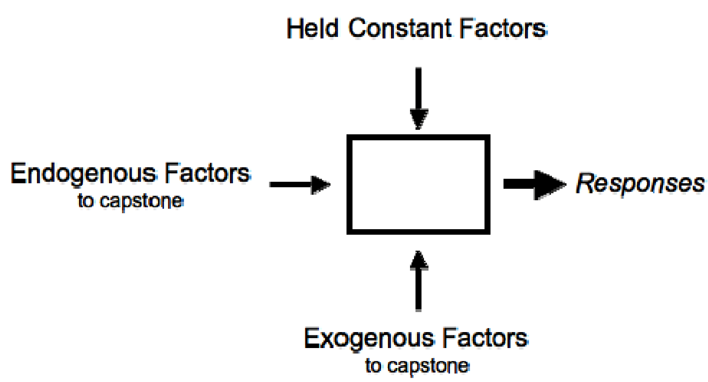


Figure 1. Capstone Evaluation Framework

Responses in Figure 1 are measures used to evaluate if students are meeting learning objectives. Responses could be quantitative, such as assessments from tests, report grades, or ABET outcomes, or qualitative descriptions of student processes or knowledge.

Exogenous factors to a capstone course include anything that varies among students but that is not directly related to the design of the course itself. Examples of exogenous factors could include demographics (e.g., gender, age, ethnicity), prior engineering experiences of students (e.g., have they worked in an engineering job before?), family background (e.g., is a close family relative an engineer?), and prior academic success (e.g., GPA).

Held constant factors to a course include anything that does not vary among students but that, if it did vary, could affect the responses. Examples of held constant factors could include major (if all students are from the same major), project advisor's department (if all students are advised by faculty from a single department), or client type (if all students worked with clients of the same type).

Endogenous factors to a course include anything that varies among student experiences as a result of the design of the course itself. Examples of endogenous factors include the two held constant examples; if a course is designed to include different majors, advisors from different departments, or to have different client types, then major, department of project advisor, and client type would be endogenous factors. In fact, noting that the same factor can be either a held constant factor or an endogenous factor depending on the course design highlights why the CVF is noteworthy - many of the held constant factors from a traditional course are endogenous factors in a capstone course.

When compared to a strategy to evaluate a “uniform experience” course like the one described in the first section, the fact that capstone courses have a large number of endogenous factors is why the CVF is novel and necessary. For a uniform experience course, the goal is to deliver a singular experience that is robust enough to be effective for all students. At the extreme, a successful traditional course would have zero endogenous factors and the held constant factors would be set such that the responses (e.g., student performance) are good even though there is variation among the exogenous factors. Hence, endogenous factors would not be needed to evaluate such a course. Endogenous factors are central to the CVF due to the unique experiences within a single capstone course.

To execute the CVF there are four main steps. While presented linearly, these steps frequently require iteration.

First, relevant responses and methods for measuring them must be identified. For instance, student performance on certain learning objectives such as being able to write effective design requirements could be a response measured by grades on a requirements report, a test given to students, interviews with students, and/or a student survey.

Second, relevant factors must be identified and categorized by type (i.e., exogenous, endogenous, or held constant) and methods to measure the factors determined. The following list of factors (Table 1) is a non-exhaustive list of possible factors to consider, based partially on factors identified by Dutson, et al., in their 1997 review of capstone literature[2]. Common measurement methods for factors could include surveys (e.g., ask students what their major is), official student records, or interviews.

Table 1 Non-Exhaustive List of Examples of Capstone Factor Types

Exogenous	**Endogenous or Held-Constant** (depending on specific capstone course)

• Demographics
  o gender
  o age
  o ethnicity
• School-related
  o GPA
  o prior course work
  o existing knowledge level of certain topics (from a pre-test)
• prior engineering experience
• prior experience working on teams
• family background with engineering
• family background with attending college
• career plans (e.g., grad school, engineering job, ...)
	• client characteristics
	  o is there a client?
	  o type of client (faculty, external industry, design contest, etc.)
	  o Engagement/role of client
	  o Amount of funding for project
	• team characteristics
	  o interdisciplinary or single discipline
	  o size
	  o MBTI/personality types
	  o Average GPA and GPA range
	• project advisor characteristics
	  o project advisor / project advisor department
	  o Advising style (boss, manager, teacher, mentor, coach, etc.)
	  o Engagement of project advisor (e.g., amount of time team meets with advisor, Is project linked to advisor's research interests?, advisor's views on the capstone course)
	  o Type of feedback given to students
	  o Was project secured by the advisor or by someone else?
	• student characteristics
	  o major of student
	  o time spent per week working on the project
	• was the project a top choice of the student?

With responses and factors defined, the third step is to collect data using the methods identified in the second step. The data could be quantitative, qualitative, or a mix of both. Finally, the fourth step is to analyze the results with appropriate approaches and draw conclusions.

Macro-level Case Studies

Inherent differences between capstone programs drive the evaluation techniques necessary to establish the variables discussed in the previous section. For each capstone program, the mix of factors (endogenous vs. constant) is unique. Inherent to the CVF is the ability to deploy a variety of evaluation techniques. Three independent studies of different capstone programs help to illustrate the flexibility inherent in the CVF.

At the University of *West*, the Interdisciplinary Capstone program is large, centrally coordinated and interdisciplinary. During the 2005-6 academic year a group of 103 engineering students enrolled in either a mechanical or multidisciplinary senior design courses participated in a study[4]. The primary response in this study was the engineering design process knowledge of students, as measured by the Design Process Critique instrument[1]. The Design Process Critique is a qualitative instrument with which a rubric is used to quantify the ability of students to recognize the steps of a design process. The two courses were nearly identical with most factors held constant. While differences in the project advisors and the type of client existed, the focus of the cited study is on the endogenous factor of if the team was interdisciplinary or from a single discipline. In addition, one exogenous factor, whether a student had prior engineering experience, was also studied. The relatively large sub-populations allowed for a quantitative statistical analysis. The results showed that the capstone course reduced the differences seen prior to the course between students with and without prior engineering experience. Students in multidisciplinary and single disciplinary capstone courses performed similarly in this study.

In contrast to the University of *West*'s Interdisciplinary Capstone program, consider a much smaller program with only fifteen or twenty students. Such a capstone program would require a more qualitative approach as it is not possible to create statistically viable sub-populations with which to study the effect of exogenous and endogenous factor variation. Key to realize with this example are that a) the CVF is a framework and is not limited to quantitative studies, and b) even if a capstone program is large, investigating the effects of factors on the capstone experience requires the total population of capstone students to be divided into progressively smaller sub-populations.

An in-depth study of the University of *East*'s Systems & Information Engineering (SIE) department's Capstone Program was undertaken during the 2007-8 academic year. The number of students involved is similar to the University of *West*. Ninety six students participated in a series of surveys and a pre and post course Design Process Critique assessment. The primary differences from the University of *West* case are that the SIE capstone program is de-centralized and only involves one discipline of undergraduate majors. Instead of a central coordinator of capstone projects, the same budget for each project, and unified deliverables for all teams, the SIE projects are each solicited by individual faculty members, the budgets for each project vary depending on the project, and the deliverables for each team are established and graded by the project advisor. In terms of the CVF, the de-centralized nature of the SIE program results in a larger number of endogenous factors that were "held-constant" at the University of *West*. The one endogenous factor at *West* that is held constant for the SIE program is the major of the students. Due to the large sample size, statistical evaluation was possible. Qualitative methods were also used. Representative results from the University of *East* study are presented in the following section.

Detailed Case Study

The capstone program offered by the SIE department at the University of *East* provides a good platform for demonstrating the CVF. The SIE capstone has been run for over twenty years and yet there has never been a method for studying the effect that variations between the individual experiences have on student outcomes. The study undertaken during the 2007-8 academic year followed the four steps of the CVF. The results of this study can be used to inform future changes to the SIE capstone program in specific and could also be used generally by other departments which employee capstone design courses.

This case study was undertaken to test the hypothesis that variation between specific capstone experiences within a capstone program lead to difference in the achievement of student learning objectives. A variety of data collection methods were used to establish responses associated with the skill, experience and knowledge of the student subjects (these were collected both before and after the capstone course). Concurrently established exogenous and endogenous variables were used to analyze the influence that variations between capstone courses have on objective achievement.

The SIE department publishes a list of departmental objectives and course objectives which allow faculty and students to understand the motivation behind the curriculum. These objectives are derived from the academic goals of the department which have a specific focus served by team-oriented design courses. Using these resources, a list of specific learning objectives for students in the capstone program was created. The objectives are the equivalent of the response described as Step 1 of the CVF.

The capstone program run by the SIE department is de-centralized with respect to organization but uniform with respect to student discipline. There are a number of constant factors that are applicable for all of the subjects involved with the study. All of the capstone students were Systems Engineering students, fourth-year University of *East* students and involved in the capstone for a full academic year. The exogenous factors which were established included the existence of prior industrial experience, prior client experience, team experience, gender and GPA. The endogenous factors are derived directly from differences between each individual's capstone experience. Some examples of endogenous factors measured in this study are; existence of external client, commitment level of faculty, commitment level of student, related previous experience of faculty advisor and the type and extent of interaction between the student and faculty advisor.

Figure 2 illustrates the representative set of the factors which comprise variation in experience within the SIE capstone program and the responses used to measure the effect of this variation.

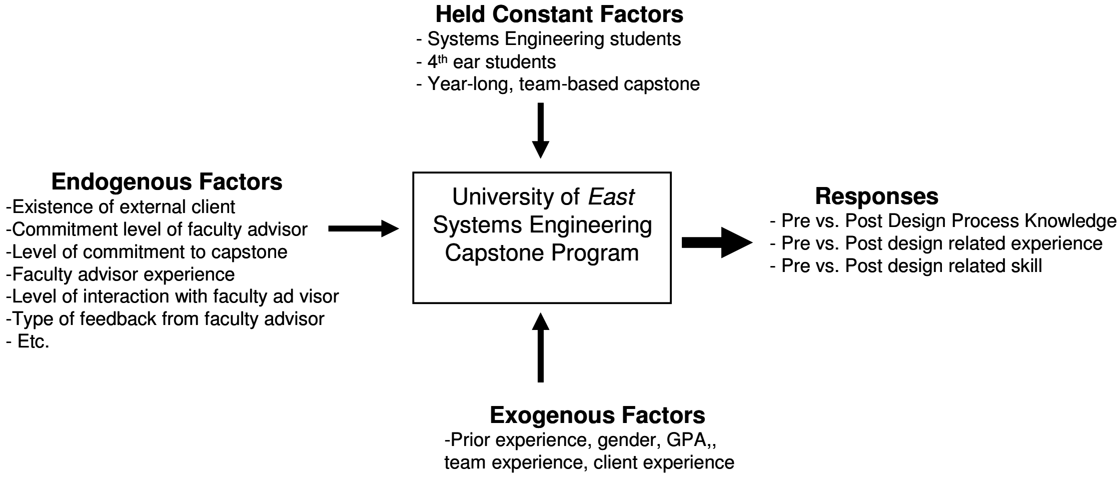
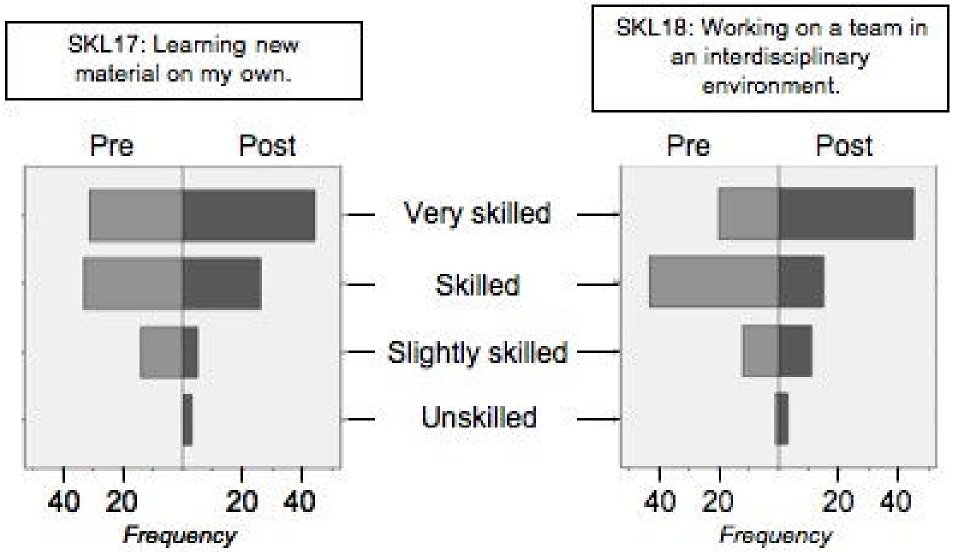


Figure 2: The Capstone Variability Framework as applied to the SIE department's capstone program

Establishing variability requires both pre and post capstone data points and the appropriate assessments with which to gather them. In the SIE study, there were three separate components to the data collection. First, the students took a self-assessment which was used to establish their self-rated experience and skill with respect to departmental objectives and to collect endogenous variable data (e.g., gender, prior engineering experience). The skill and experience questions were identical and were intended to understand both the student's exposure and competence to specific types. Examples of the topics are: Generating alternative solutions, using a systematic process, and applying decision tool to select among a set of alternatives.

An example of the type of data collected is shown in Figure 3. This type of data allows for a close look at the type of skill, experience and knowledge acquisition that arises from the capstone program.



(a) (b)

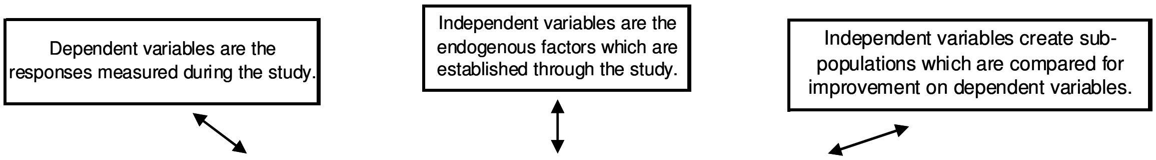
Figure 3: Example of dependent variable data collected during pre and post survey.

In Figure 3.a, more students self-report being very skilled with learning material on their own after a capstone experience than before. Similarly, in Figure 3.b, more students self-report being very skilled with working on a team in an interdisciplinary environment after the capstone experience than before. The paired data is analyzed using a Wilcoxon signed ranks test: for the two examples shown in Figure 3, results from this analysis show that both changes are statistically significant at $\alpha=0.05$ (SKL17 "learning on my own": n=78, p=.035; SKL18 "teamwork in interdisciplinary environment": n=76, p=.009).

The study also used the Design Process Critique which employs a rubric to score written responses by students that represent the design process knowledge of students. The Design Process Critique asks students to evaluate a proposed process for addressing a simple design problem. The process both includes and excludes important parts of the design process. Students are given scores for their ability to recognize the following design steps; needs identification, idea generation, analysis and decision making, building and testing, layout and iteration, timing and documentation. Both of these student assessments were given both before and after completion of the capstone course. The changes in experience, skill and design process knowledge were attained and the results analyzed statistically.

The third data collection component was a survey of the faculty advisors which collected a faculty perspective on certain endogenous factors such as client involvement and faculty expertise with the technical topic of the project and with design in general.

A wide variety of exogenous and endogenous factors were established and used to study the relationship between variability and effect of the capstone experience. One quantitative method of analysis used during the SIE study was to compare the pre and post results of a self-reported student survey. An example of the type of results found during this analysis is presented in Figure 4.



Dependent Variables	Independent Variable	Most Improved	Least Improved
Skill: Generating alternative solutions.	Team feedback from faculty?	Excellent	Adequate or Less
Experience: Using systematic process.			Adequate or Less
Experience: Applying decision tools.		Excellent	

Figure 4: The quantitative analysis studies the interaction between dependent and independent variables.

The dependent variable shown in Figure 4 concerns the quality of feedback students felt they had received from their faculty advisor. Figure 4 shows that students who responded "excellent" to this question were more likely to have improved with respect to their ability to generating alternative solutions and the amount of experience with applying decision tools. Those students who received adequate or lower feedback improved the least with respect to their having experience with using a systematic process to meet user needs. All results in Figure 4 are based on a Kruskal-Wallis test with $\alpha<0.05$.

Non-statistical analysis, such as the one found in Figure 5, was based on graphical examination of the data. Figure 5 implies that the students are more likely to self-report an increase in experience versus an increase in skill with regard to “managing the budget on a large-scale project”.

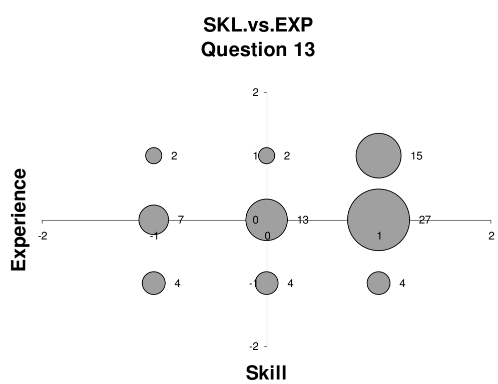


Figure 5: Graphical analysis of question 13, “Managing time on a large-scale project”, a comparison the change in a student’s “experience” versus their change in “skill”.

This same type of analysis, establishing the significance of a relationship between the responses and factors was used against all of the pre and post data collected. The Kruskal-Wallis, Mann-Whitney and Wilcoxon statistical tests were used along with post-hoc qualitative evaluation of the data. Using the endogenous and exogenous factors, established in the pre and post surveys, the data was grouped according to response. For example, one question on the student survey asked; "have you ever completed a project for a client?"; this question established an exogenous factor concerning prior experience. Splitting the data into two groups, those with prior client experience and those without, it is possible to look at the differences between response. In this example, it was found that students with no prior client experience are more likely to increase their skill and experience with regards to "working with a client". *Appendix I* contains a table that displays instances where the grouping of sub-populations revealed significant differences in how the responses change from before to after the capstone course. In the following examples (drawn from the data in Appendix I), a higher score indicates a larger increase (change from before to after capstone) in experience, skill or knowledge over the course of the capstone.

Response	**(Sub-population with significantly higher score)**
Skill in leading a team	(Good feedback from faculty member)
Experience applying decision tools	(Excellent team feedback)
Experience analyzing alternative solutions	(Unhelpful client)
Using a systematic process	(Females)
Experience tracing requirements/needs	(3.5-4.0 GPA)
Skill generating alternative solutions	(No related summer job)
Skill implementing a design	(Strongly enjoy working on teams)

The first three factors in the example are endogenous to the capstone experience while the last four are exogenous.

Due to lack of a control group in this particular study, there can be no causation implied. However, the ability to establish that variability in the capstone experiences leads to variability in the student outcomes is an important result. A more qualitative approach was also used in the SIE study in order to assess strengths and weakness of the program. Students and faculty were asked to assess strengths and weaknesses and the results were organized to ascertain which aspects of the capstone were most often recognized as strong or weak. The most commonly cited strengths were "exposure to real world problems" and "real clients". The most commonly cited weaknesses were "too little time" and "inconsistency between advisors". This type of analysis is particularly important as a feedback tool for the department.

Discussion and Conclusion

The proposed capstone evaluation framework is aimed at embracing the unique aspects not only between capstone courses, but more importantly within them. Based on the macro-level cases, the framework is theoretically very flexible in its ability to accommodate different capstone courses and different institutions. Further work is needed to empirically evaluate the framework at a wider array of unique capstone programs.

Results from the in-depth case study at the University of *East* highlight several strengths of the capstone evaluation framework. First, the framework was useful and effective at structuring an evaluation that incorporated the complexities of the SIE capstone program. Secondly, the framework was shown to work with a variety of different assessment tools. Most tools were ultimately quantitative (even if they began with qualitative information from students), but a few qualitative components showed that the framework is not limited to one type of assessment information. The framework was very useful in structuring the analysis and data collection and thereby led to a huge amount of data.

Limitations of the framework were also experienced in the in-depth case. It takes a very large population to provide significant sub-populations once one starts looking at more specific variation. In the same vein it is almost impossible to create a control population when there are so many factors varying internally. This is compounded by the difficulty in providing a un-biased quantitative assessment of many of the endogenous factors. These limitations can be addressed in the future with further development of assessment tools and as further studies increase the number of data points.

In future work, the framework needs to be compared against a larger variety of capstone programs. In order to achieve important results within the framework it is necessary to continue to build a comprehensive set of assessments which can be used to facilitate understanding of the role that variability plays in capstone courses. As the field of engineering education strives to understand capstone programs, it is important to continue to address the innate challenges associated with assessing such a complex class.

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Appendix I:

Analysis of Variance of Dep. Variables based on Student Ind. Variables

The following table displays when the sub-populations created by the student independent variables had significant differences. The population that was ranked higher or lower is shown under "reason for significance".

		Dependent Variable	P <.05	Independent Variable	Population with high mean rank?	Populations with low mean rank?
Capstone Emphasized	Large-Scale Project	13 EXP: Managing budget	0.046	Working on teams	Agree	
		14 EXP: Working with a client	0.002	Client Experience	No	
		14 EXP: Working with a client	0.005	Helpful client?		Non-Factor
		14 SKL: Working with a client	0.014	Client Experience	No	
		14 SKL: Working with a client	0.017	Importance of faculty?		Less Helpful
	Communication	12 EXP: Leading a team	0.032	Helpful client?	(Essential + Non Facto	Unhelpful
		12 SKL: Leading a team	0.024	Team feedback from faculty?	Good	
		16 EXP: Writing technical reports	0.002	Gender	Females	
		16 EXP: Writing technical reports	0.002	Representation	Under-Represented	
		16 EXP: Writing technical reports	0.019	Importance of capstone?	Strongly Agree	
		16 SKL: Writing technical reports	0.041	Individual feedback from faculty?		Excellent
	Real-world experience	17 EXP: Learning on my own	0.025	Individual meeting with faculty	Once a semester or less	
		19 SYS: Exposure to real-world activities	0.026	Individual meeting with faculty	Once a semester or less	
Systems Methodology	Systems Methodology	1 SKL: Using systematic process	0.036	Gender	Females	
		1 EXP: Using systematic process	0.020	Gender	Females	
		1 EXP: Using systematic process	0.018	Team feedback from faculty?		Adequate, poor or none
		2 EXP: Identifying requirements	0.033	Working on teams	Strongly Agree	
		4 SKL: Generating alternative solutions	0.015	Gender	Females	
		4 SKLGenerating alternative solutions	0.049	Client Experience	No	
		4 SKL: Generating alternative solutions	0.03	Team feedback from faculty?	Excellent	Adequate, poor or none
		4 EXP: Generating alternative solutions	0.041	Gender	Females	
	Systems Tools	3 SKL: Developing metrics	0.037	Gender	Females	
		3 SKL: Developing metrics	0.045	Summer "systems" job	No	
		5 SKL: Analyzing alternative solutions	0.024	Summer "systems" job	No	
		5 EXP: Analyzing alternative solutions	0.024	Helpful client?	Unhelpful	essential + non-factor
		6 SKL: Applying decision tools	0.024	GPA	<3.0	3.0-3.5
		6 EXP: Applying decision tools	0.041	GPA	<3.0	****************
		6 EXP: Applying decision tools	0.030	Individual feedback from faculty?	Excellent	
		6 EXP: Applying decision tools	0.048	Team feedback from faculty?	Excellent	
		6 EXP: Applying decision tools	0.002	Helpful client?		essential + non-factor
	Design & Test Complex Systems	7 SKL: Implementing a design	0.049	Working on teams	Strongly Agree	
		7 EXP: Implementing a design	0.037	Importance of capstone?	Strongly Agree	
		9 SKL: Implementing a test-plan	0.004	Individual feedback from faculty?	No Feedback	
		11 EXP: Tracing requirements/needs	0.016	GPA	3.5-4.0	
Understanding of Systems Engineering		20 SYS: S.E. effect on societial systems	0.038	Working on teams		Slightly Agree or Less
		21 SYS: S.E. effect on societial systems	0.027	Time spend on capstone	6+	
		22 SYS: S.E. effect on societial systems	0.049	Importance of capstone?	Agree + Strongly Agre	Disagree + Slightly agree
		23 SYS: S.E. effect on societial systems	0.043	Effort put into capstone		Slightly Agree or Less