AC 2010-1897: DESIGNING SUCCESSFUL DESIGN PROJECTS

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Designing Successful Design Projects

Abstract

The importance of design is increasing in undergraduate engineering programs. Design is seen by proponents as a vital element of learning engineering. Compared to courses which focus on engineering analysis, design courses emphasize application of a broad spectrum of knowledge in narrow contexts. The importance of design courses is magnified by their impact on students and their disproportionate importance for assessment and accreditation. One element of design courses, particularly capstone courses, that has received little attention is how to characterize and choose suitable design projects.

To better understand what aspects of design projects lead to successful capstone design experiences for students, six years of evaluation data on electrical engineering capstone design projects at a large, public research university were reviewed. Additionally, transcripts from four years of a capstone design course end-of-semester "after action review" by faculty, students, and teaching assistants were reviewed. From this work several characteristics of "successful" capstone projects emerged. While a definition of success is, of course, highly dependent on program specific outcomes, for this study success was defined as a project that was: judged by both students and faculty to have been completed successfully, allowed meaningful contributions by most students on a team, and satisfactorily met written and/or oral reporting requirements. Additionally, where available, comments from program graduates were used to identify successful projects.

The specifics of projects varied widely, however several characteristics shared by successful capstone design efforts were identified. One characteristic included projects that were able to be repeated, or iterated, several times during the semester in which the project was given. A second characteristic of successful projects were that they did not fall to either extreme of the technology readiness level (TRL). The third characteristic is that projects did not draw on knowledge beyond which students had been exposed to or outside the discipline. These results provide some guidance on relatively simple ways to improve outcomes in capstone courses.

Background: Capstone Design

Design as an activity is increasing in importance in undergraduate engineering programs both due to ABET criteria and an overall recognition that engineering needs to be more hands-on[1]. Supporters view design as a necessary aspect of learning engineering that plays a unique and important role in the engineering degree program. As a results design is being introduced across the curriculum from freshman courses to the traditional capstone programs. The importance of design, particularly capstone, courses arises both from their purported impact on students and because of their disproportionate role in assessment and accreditation in many program[2].

Despite the importance of design courses to program outcomes, their format varies widely and outcomes are not standardized across programs. For the purposes of this paper design courses are classified broadly into two discrete but usually overlapping sets: design problem courses and design process courses. Design process courses teach students the process of design, usually through design cycles and effort management tools such as Gantt charts and work breakdown structures. Since these courses are amenable to more traditional pedagogies, textbooks have been developed to support design process courses[3]. Design problem courses, on the other hand, emphasize application of a broad spectrum of knowledge in a narrowly defined context. They typically use pedagogies of project- or problem-based learning[4]. For both types of courses the desired course outcomes can be difficult to define clearly since typically faculty want design courses to be developmentally transformative; i.e. help the student actualize themselves as an engineer by taking on the role of an engineer and actively participating in the culture of engineering.

This paper focuses on design project courses, but does not address how to teach design or what an ideal design course should be. Here the emphasis is on the design projects. Specifically, since learning occurs in the context of a design project the question asked is "do the specific context and details of the design project impact the course outcomes?" To determine if certain types or classifications of design projects lead to more or less successful capstone design experiences for students, six years of evaluation data on electrical engineering capstone design projects at a large, public research university were reviewed. Additionally transcripts from four years of an end-of-semester "after action review" of a capstone design course by faculty, students, and teaching assistants were reviewed as well as artifacts from design projects if available.

Previous Work on Design Project Characterization and Design

There has been a great deal of work on design processes and ways to improve, manage, and teach them. However there has been much less work on design of design projects. Dutson et. al, reviewed the literature on capstone design courses[5] over a decade ago. Unlike categorization here into process and project this paper reviews other methods to categorize courses including "simulation" vs. "authentic involvement" and "economic evaluation" vs. "construction". These authors review projects in terms of the project sources, project completion requirements, and cost. However projects are not categorized beyond these three characteristics.

Dym and co-authors[6] review aspects of design thinking, placing it in the context of project-based learning and providing evidence to the effectiveness of this technique for capstone and cornerstone courses. One of the research questions posed by these authors is "What are the best proportions of problems, projects, teamwork, technology, and reality for a given state of student development?".

Sadler, Coyle, and Schwartz report on the design of effective projects in middle schools[7]. They find that a clear goal that can be easily evaluated is critical for this level student. Similarly, allowing iterations are important so that students in this age group can let evaluations of their previous actions guide future actions. An additional factor in project choice was having unambiguous outputs with large dynamic range so that intrinsic noise or experimental errors do not confuse results. Competitions should be "against nature" rather than against peers. Finally, for middle school students beginning design projects with a clearly outlined prototype design rather than with a "blank slate" improves engagement. Similar considerations are briefly discussed in project selection in a college freshman design course[8].

For capstone design courses (typically taken by college students in their senior year) a number of papers have mentioned aspects of successful design projects as part of a summary of the effectiveness of capstone courses. The factors reported as leading to a successful project include "being viewed as worthwhile"[9], related to the engineering discipline[9], the difficulty of beginning with very open-ended problems[4], and choosing "modern and emerging technologies with which most of the students would have some familiarity"[10].

Research Questions and Reviewed Artifacts

To better answer the questions "*Does project selection impact outcomes in capstone courses?*" and "*What aspects of projects positively impact capstone outcomes?*" data archived from ABET evaluation activities at a large, public research university were reviewed. This data included written and oral project reports, rubric-based evaluation of the reports by faculty and outside evaluators, written project descriptions given to students, and scores from rubrics used for project demonstration evaluation. Additionally transcripts from four years of an end-of-semester “after action review” by faculty, students, and teaching assistants who participated in a capstone design course were reviewed. The after action review summarized the positive and negative results of the course, sought suggestions for change, and allowed open discussion of course and project issues.

In the capstone course under consideration, the teaching duties rotate between different faculty members, usually on a semester-by-semester basis. Lacking a way to measure faculty design expertise, no attempt was made to account for the experience of those faculty who taught the course over the period investigated. None of the faculty, however, had any formal training in design processes and the effort expended by each faculty member was reported to be approximately equivalent. Although one faculty member is assigned as the course instructor, each team had a separate faculty mentor, and teams were evaluated by their mentor and two other randomly assigned faculty. The format of the course included little formal instruction in the design process, teaming skills, project management, or fabrication techniques. Rather, these skills were taught in a pre-requisite design course taken immediately prior to the capstone course. Teams generally spent the entire semester working on their project with relative independence except for mandatory weekly meetings with the faculty mentor. Due to the rapid rotation of instructors, teams were generally constituted to be heterogeneous by grade point average or student performance in previous courses that had a design element. Thus it was assumed that team composition had approximately the same impact on the results of the project over the period reviewed by this study. Previous measurements in the program investigated have shown that grade point average is uncorrelated with performance in the capstone course. Similarly, all projects had the same budget, so project resources were assumed to have little impact. For a few of the capstone projects reviewed, teams were arranged by the instructor to consist of entirely high-performing or low-performing students. The results of these projects were removed from the data considered in this investigation.

Since the course instructor changed on a regular basis, the projects given in the capstone design course were highly heterogeneous. They ran the gamut from industry sponsored projects to multi-university competition projects such as NatCar and IEEE regional competitions to projects suggested by individual faculty members or students. With the exception of the competitions, generally projects are only given once and not repeated. A review panel of three faculty members chooses projects each semester to help ensure the submitted projects are at a level of difficulty suitable for student teams. Due to limited financial resources, one of the selection criteria are to keep overall project costs below $500 US; students are reimbursed expenses up to this amount if their project is judged to be functional at the conclusion of the course.

Written reports are submitted by each team following the conclusion of their project. Experience shows that most teams write the report following conclusion of the project rather than document the project as it progresses. Over the interval of this study, changes were made by various instructors in the relative weighting of written reports to the final course grade which may have resulted in varying degrees of effort by students. While the report is submitted by a team, when sections of the report are written by individuals, the team is required to indicate who the author is. Reports were scored by multiple reviewers; for approximately half the reports used in this study the reviewers arrived at a consensus score while for the other half the mean of reviewer scores was used; for those reports that used mean scores, there was no attempt made to calibrate reviews. This change in scoring was due to changes in the department accreditation process over the time interval measured. Although reports were scored on multiple factors, only the overall score was used in this preliminary study to keep data sizes manageable. Written project reports also provided information that was used to rate each project on the six factors described in the next section.

Oral reports were made one or two weeks prior to project demonstrations, and thus represent the state of the project at a "nearly finished" state. Reports are done by teams in a public forum, and like the written reports are scored by multiple reviewers using a rubric. Due to changes in instructor and department assessment methods, oral reports also had changes to the grade weighting and how the mean score was determined over the period for which data was collected for this study. It should be noted that in the program studied students are not required to take a speech communications class, and few classes provide opportunities for oral presentations. For many students the capstone oral presentation was the first opportunity to present the results of engineering work formally.

Rubric-based scores from design project reviews were also investigated. The project review is the due date for the project, and the design team demonstrates the functionality of their project for the faculty mentor and two faculty reviewers on multiple factors that constitute project success. For this study only the overall score of project success was used. A common rubric is used by all three reviewers. While reviewers are supposed to reach a consensus score, in some cases this did not occur and the mean score was used.

Categorization of Factors to Rate Design Projects

Projects were categorized on six factors, each which was hypothesized to contribute to successful project completion. For each factor a rating was assigned based either on existing scales, or scales developed to rate the projects as described below. Ratings were determined from project descriptions, reviews of project demonstrations, and project documentation. The six factors used to rate projects were:

1. The technological readiness level (TRL)[11], originally developed by the Department of Defense and NASA to determine how ready a new technology is to be deployed. Nine readiness levels are used to classify technology from proof of basic principles (1) to sustained successful operation in the field (9).

2. A rating of system complexity was developed from general ideas of complexity in natural and manmade systems[12], and work in industry that rates system complexity by the number of interconnections between subsystems[13]. Other measures of complexity used in different fields, such as McCabe complexity (related to the number of possible execution paths through the code) in software development[14] were considered but deemed inappropriate. To the author's knowledge no validated complexity rating scale is available that is suitable for easily rating student design projects ; discussions with experts on complexity theory did not turn up any easily adaptable scales or rubrics. Thus, projects were rated as:
   - 1 = small number of subsystems with one-way, non-interacting, and linear flow of signals (no loops).
   - 2 = some aspects of 1 and some aspects of 3
   - 3 = subsystems have bi-directional flow of signals or information, system has some feedback loops or ways output can affect input.
   - 4 = some aspects of 3 and some aspects of 5
   - 5 = idea of functional decomposition does not hold, system is tightly coupled and sensitive to small changes.

   Since complexity is not yet well-characterized[12], the scale was designed to be simple at the expense of completeness.

3. The projects were reviewed for the opportunity teams had to iterate their designs. The ability to iterate was determined, if possible, from statements made by the team in reports as well as the project constraints and detail. Both time and budget constraints were considered as well as the overall difficulty of the project and the detail with which successful project outcomes were described. A five point scale was used:
   - 1 = no chance for iteration,
   - 2 = a chance to partially iterate subsystems,
   - 3 = the team having a chance to perform at least one iteration of the each subsystem,
   - 4 = a chance for complete system iteration,
   - 5 = the chance for multiple iterations.

   This was a difficult factor to measure accurately from the available evidence and may be subject to significant errors.

Initially a five point scale was considered for all rating factors. However a preliminary evaluation of student artifacts showed that some of the originally formulated scales were too broad, and none of the projects fit all criteria. Thus for the following factors a four point scale was used. Note that other capstone courses with different emphasis may find five point scales offer more discernment.

4. The fourth criteria was the amount of knowledge that the project required to be successfully completed that was either outside of the discipline of electrical engineering or was not taught in undergraduate classes. Here knowledge is defined as factual, theoretical, or conceptual rather than procedural or tacit[15]. A four point scale was used with:
   - 1 = the knowledge required to complete the project was covered in requisite classes,
   - 2 = the knowledge was in electrical engineering and at the undergraduate level, but was taught in elective courses or not covered in the curriculum,
   - 3 = undergraduate level knowledge outside electrical engineering (i.e. mechanical systems), or knowledge typically taught at the graduate level in the discipline.
   - 4 = advanced knowledge outside the discipline.

5. Whether or not a project required special fabrication or test and measurement techniques covered the procedural or tacit knowledge dimensions of knowledge. Again a four point scale was used with:
   - 1 = skills students had been taught in undergraduate classes for which they had ready access to equipment,
   - 2 = skills and equipment that were available in the department, but were not typically taught in undergraduate classes,
   - 3 = advanced electrical engineering fabrication techniques that were more specialized or simple fabrication techniques from other disciplines,
   - 4 = advanced fabrication techniques that required specialized knowledge.

6. The final criterion was the amount of local, easily access expertise available for the project. Previous work in this program[16] has demonstrated that students receive little formal training in how to perform research, thus it was hypothesized that project for which local expertise was not available would have lower probabilities of success. A four point scale was used with:
   - 1 = expertise available from students on the team or the mentor, instructor, or TAs;
   - 2 = expertise available within the department;
   - 3 = expertise available on campus or through on-line forums,
   - 4 = a need to track down expertise from off-campus organizations.

The initial five point scale used for expertise had the rating of four correspond to off-campus expertise that was readily available and five correspond to expertise that was more specialized. One reviewer of this paper pointed out that splitting the first item to be expertise within the team and expertise from the mentor, instructor, or TA would offer additional discernment.

The factors defined above were chosen based on the review of the evidence and observation of capstone design teams over the period of the investigation. With the exception of the technology readiness level, little work has been done to allow categorization of engineering design projects on these factors in a simple way, and thus the rating scales should be considered preliminary and not validated. As will be discussed subsequently, this raises some questions about how independent these factors are and the accuracy to which projects can be categorized.

Aspects of successful and unsuccessful projects.

To determine if project definition impacts success in capstone projects, projects were rated on each of the scales above and a multiple regression to scores from oral and written reports and design demonstrations was performed to determine how much of the variance in team performance could be explained by the six project definition factors defined above.

Of the six factors defined to judge projects, several were weakly or strongly correlated with each other at a significant level. The TRL was negatively correlated with complexity ($r = -.34$, $p < .05$), the need for knowledge outside the discipline ($r = -.34$, $p < .05$) and the need for special fabrication techniques ($r = -.041$, $p < .001$). Thus projects that are more at the prototype stage have less complexity, less need for knowledge outside electrical engineering, and are amenable to simpler fabrication methods. The complexity of the project was strongly positively correlated with the need for knowledge outside the discipline ($r = .70$, $p < .001$) and weakly positively correlated with the need to conduct research or seek outside the department for information ($r = 0.37$, $p < .05$); again these correlations are expected since complex projects draw from multiple sources. The results above are not at all surprising, but provide some support for the validity of the rating scales. The need for external expertise and need for interdisciplinary knowledge seemed to measure the same factor since they were correlated at $r = 0.72$ with $p < .001$. The number of iterations the team could perform during the capstone course was negatively correlated with interdisciplinary knowledge ($r = -0.52$, $p < .001$), the need for special fabrication techniques ($r = -0.51$, $p < .001$), and the need to conduct research or seek external expertise ($r = -0.38$, $p < .05$). The reason for this is not clear, however it is hypothesized that projects which fall within students' expertise and fabrication skills proceed more rapidly, allowing more iterations. The factors of tacit/procedural and factual/conceptual knowledge overlap at $r = 0.55$ with $p < .001$, likely indicating these scales measure many of the same factors.

Simple linear correlation of the written and oral reports and the rubric-graded demonstration indicated that only demonstration scores and written report scores were correlated with any of the scales. Oral presentation scores were completely uncorrelated with all scores ($|r| < 0.1$, $p > .6$). The likely explanation is that oral reports require skills or are judged by attributes that aren't related to the project characterization factors used here.

Scores on project demonstrations are positively linearly correlated with the number of iterations ($r = 0.53$, $p < 0.001$), and negatively correlated with the need for interdisciplinary knowledge ($r = -0.37$, $p < .001$) and the need for special fabrication techniques or measurement skills ($r = -0.44$, $p < .005$). In contrast with the scores on project demonstrations, written report scores are negatively correlated with the measure of project complexity ($r = -0.35$, $p < 0.05$) , the need for theoretical/conceptual knowledge outside the discipline ($r = -0.39$, $p < 0.05$), and the need to go outside the department for expertise ($t = -0.45$, $p < 0.05$). The correlations are not as significant as those for the project demonstrations. Since demonstrations more likely measure the actual work of or product produced by the design team, it is not surprising demonstrations are more strongly affected by project selection and definition than are reports.

While the technology readiness level is not linearly related to the rubric scores of capstone project demonstrations, when plotted against the TRL the demonstration score, S, has a quadratic dependence given by $S = (TRL - 6)^{-.13} + 3.3$. Thus demonstration scores are highest (mean of 3.3) for a TRL of 6. This technology readiness level is defined as "*Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, tested in a relevant environment. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment*."[11]. Thus capstone project which have students create prototype systems generally scored better than those which are more speculative or research-oriented (low TRL) or projects which have teams build a more proven or operation-ready project. Note that the quadratic dependence is weak; on a five point scale a one point difference in score occurs ±3 TRL points from a TRL of six. The 95% confidence interval is 2.1 points and the 50% confidence interval is 0.7 points on the 5 point scale used for project demonstration evaluation.

Linearizing the TRL and performing a multiple regression to the project demonstration score allows a determination of the relative impact project selection has on the variation in project demonstration scores. Both four and three factor models were considered. The four factor model looked at TRL, iterations, knowledge, and skills while the three factor model averaged knowledge and skills due to their high positive correlation. The three factor model performed better than the four factor model giving the following results for N = 40 samples:

Table 1: Multiple Linear Regression on Project Demonstrations

Standardized Regression Coefficient	Coefficient of Determination	p value
$\beta_{TRL} = -0.16$	$R^2 = 0.38$	$p < 0.001$
$\beta_{iterations} = +0.32$		
$\beta_{knowledge} = -0.28$		

The project definition/selection criteria defined above explain over 30% of the variation in project demonstration scores with the ability to undergo more iterations having the strongest effect followed closely by the amount of knowledge outside the discipline required to successfully complete the project. The effect of the technology readiness level discussed above is approximately half of the strength of the other two factors.

A similar multiple regression was performed for performance on the written report scores for each of the factors that were significantly correlated. The overall model was not significant at the 5% level, but was at $p < 0.1$. The results are shown in the table below:

Table 2: Multiple Linear Regression on Written Reports

Standardized Regression Coefficient	Coefficient of Determination	p value
$\beta_{complexity} = -0.12$	$R^2 = 0.21$	$p < 0.1$
$\beta_{expertise} = -0.37$		

Project factors *may* explain about one fifth of teams' performance on written reports with the largest effect being the amount of local expertise available when students need to consult with experts. The complexity of the project has a much smaller effect. While this conclusion is highly tentative, the result can be explained by the facts that: 1) if local expertise is lacking students are unable to have difficult concepts explained leading to poor explanations in reports, and 2) few students receive training in complex systems.

To guide analysis of the data, notes from capstone after action reviews (AARs) were reviewed and some students were interviewed as a "sanity check" on the results and analysis method. Relatively few comments were made by students about projects; either students assumed that the projects chosen by faculty were at an appropriate level for their abilities or were unwilling to comment on the project criteria. The majority of comments were about personnel, teamwork, and class management or grade assignment issued. The only coherent theme in student comments supported the results found by the analysis of project classification factors. Specifically students commented on the lack of training in how to assemble projects to commercial or industrial standards (quality), which supports the lower performance seen at high TRL.

Conclusions and Impact on Practice

This paper reported initial results on analysis of how the choice of design projects, as classified by six factors, impacted scores on project demonstrations and written project reports over four years of a senior capstone design course. The focus of the study was looking at what aspects of design projects impact performance. Six factors were defined: the technology readiness level, system complexity, number of iterations possible, two measures corresponding to factual/conceptual and procedural/tacit knowledge, and whether expert help was locally available. With the exception of technology readiness level, four or five point Likert scales were developed for this analysis since appropriately simple project rating scales do not exist to the author's knowledge. Ratings on each of the factors were determined from the project descriptions, review of project documentation and reports, and the project demonstrations.

In summary, students' performance on project demonstrations depends on the types of projects they are given. Analysis showed that over 30% of the variance in project demonstration scores may be explained by the project factors examined in this study; the remainder of the variance is likely due to student ability, motivation, and team factors. The most important factor is the ability of teams to perform multiple iterations of the design project. Design projects that are not amenable to multiple iterations reduced students' chance of success. Of almost equal importance to multiple iterations was for projects to draw from knowledge within the teams' discipline of electrical engineering. Projects which required knowledge outside of what students learn in the degree program received lower scores on project demonstrations. Projects with a technology readiness level around six were found to score higher than those that were more towards the research (lower) end of the scale or those that required a more finished and tested product. The impact of the TRL was less than the other two factors, however.

While scores on written project reports could be explained to some extent by the project's complexity and availability of local expertise, the model was significant at $p < 0.10$ but not $p < 0.05$. Oral presentation scores were not correlated with the factors used to rate projects. It is interesting to note that oral presentations are used by 94% of engineering programs to evaluate capstone course and written presentations by 91%[2]. Since in this limited study oral presentation scores are independent of the project definition factors and written scores are, at best, weakly explained, it may be that evaluation of written and oral artifacts measures different learning outcomes than do project demonstrations or trials. While the oral and written communication helps programs achieve ABET outcomes, capstone faculty should determine if they are adequate proxy measures for course outcomes. It is also important to distinguish scores from learning; this study examined the how variation of scores depends on a design project but did not directly measure student learning.

While this study is preliminary and the factors used to analyze design projects have not been fully validated, there are several recommendations that can impact practice in capstone design courses:

- Since project definition and selection plays a role in whether capstone teams succeed, choosing the right projects may be a relatively simple way to improve outcomes in capstone courses.
- Projects should minimize the need for factual, conceptual, or procedural knowledge that is not directly taught in the degree program.
- Projects which require fabrication techniques, facilities, or tacit knowledge which students have not acquired should ensure that students have access to facilities and the opportunity to receive training in specialized techniques.
- Technology readiness levels can be used as a quick guide to project suitability, with a TRL of approximately five to seven optimal for the program examined in this study. Other programs that prepare students differently may have different results or require different outcomes.

It is important to state that while this paper identifies characteristics that are correlated with more successful projects, the design of capstone courses and project selection should ultimately be determined by the desired course outcomes. A retrospective look at capstone project using the scales developed here can help programs determine if successful projects meet desired outcomes.

The results presented here are an initial attempt to develop classifications that can be used to characterize capstone design projects. Given the ability of this initial work to explain variation in team performance and the relative ease of selecting more appropriate projects compared to other course or curriculum changes, it would be worth performing a more carefully designed study. Work suggested by this study includes investigating other factors that can influence project success, developing and validating improved measurement scales for significant factors, and developing evaluation guides, checklists, or rubrics to help ensure projects are suitable for the student population. To address the last point, three rubrics have been developed for capstone projects which fall at different points on the technological readiness level scale. These rubrics are currently in use in the program discussed in this paper and are provided in the appendix for those who may wish to give projects which fall at different points on the TRL spectrum.

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Appendix

TRL Level 1-4 Demonstration Scoring Rubric

Evaluator: **You are NOT assigning a grade to students**. You are rating the capstone team's demonstration on the criteria listed below on a one to five scale. Your goal is to provide ratings that help the instructor distinguish the quality of students and team projects both in comparison to other teams this semester and in comparison to teams from previous semesters.

Students: It is up to you, the student, to demonstrate to the evaluator that you meet the evaluation criteria defined below. It is not the responsibility of the evaluator to ask these questions or elicit responses from you. Be Proactive!

Rating Scale: Fractional ratings such as 2.6 are encouraged
1 = Unacceptable performance, I would fire this person if they worked for me, this defines failure.
2 = Needs improvement, clearly in the bottom 20% of students, I am disappointed in the quality.
3 = Meets but does not exceed expectations, middle 50% of students, about what I thought I'd see.
4 = Exceeds expectations, top 20% of students, I was pleasantly surprised.
5 = Outstanding, I want to hire this person to work for me, at the top of the rating scale.

Team/Project Ratings

Rating Criteria	Rating (1-5)
The work was technically sound. I did not find any major errors.	
The analytic or numerical modeling of the project was valid.	
The team generated testable predictions, measured them, and used this to validate their theory.	
If I did not know this field well I would have learned something listening to this demonstration	
The team showed familiarity with prior work, the project was thoroughly researched.	
The demonstration showed the project met its goals. The project was a success.	

Ratings of Individual Students

Rating Criteria					
This student understood and explained the importance of their role in the project.					
The student made a meaningful contribution to the project outcomes.					
The student understands the goals and background of the project.					
The student discussed their part of the project technically, using correct terminology.					
The student's work was technically correct. They made no major errors.					
The student understood the context of the problem. They can discuss social, technical, economic, or environmental consequences of this work.					

TRL Level 5-7 Demonstration Scoring Rubric

<u>Evaluator</u>: **You are NOT assigning a grade to students**. You are rating the capstone team's demonstration on the criteria listed below on a one to five scale. Your goal is to provide ratings that help the instructor distinguish the quality of students and team projects both in comparison to other teams this semester and in comparison to teams from previous semesters.

<u>Students:</u> It is up to you, the student, to demonstrate to the evaluator that you meet the evaluation criteria defined below. It is not the responsibility of the evaluator to ask these questions or elicit responses from you. Be Proactive!

Rating Scale: Fractional ratings such as 2.6 are encouraged
1 = Unacceptable performance, I would fire this person if they worked for me, this defines failure.
2 = Needs significant improvement, I expected better of a senior engineering student.
3 = Meets but does not exceed expectations, about what I thought I'd see from a engineering senior.
4 = Exceeds expectations, better than I expected from a senior engineering student.
5 = Outstanding, I want to hire this person to work for me, at the top of the rating scale.

Team/Project Ratings

Rating Criteria	Rating (1-5)
The team described the purpose of their prototype. They clearly described what they were trying to build	
The work was technically sound. I did not find any major errors.	
Modeling was compared to and validated by measurements. Simulations helped in improving the design	
The team explained the design process. I understand why they made design decisions that resulted in improvements to the prototype	
The prototype they demonstrated was well built and rugged enough to be thoroughly tested.	
The team presented measured specifications of their prototype. They were able to describe how the measurements were performed and repeat them if applicable.	
The team knows how to improve the product and what bugs or deficiencies it has. They frankly discussed needed improvements.	

Ratings of Individual Students

Rating Criteria					
This student understood and explained the importance of their role in the project.					
The student made a meaningful contribution to the project outcomes.					
The student understands the goals and background of the project.					
The student discussed their part of the project technically, using correct terminology.					
The student's work was technically correct. They made no major errors.					
The student understood the context of the problem. They can discuss social, technical, economic, or environmental consequences of this work.					

TRL Level 8-9 Demonstration Scoring Rubric

Evaluator: **You are NOT assigning a grade to students**. You are rating the capstone team's demonstration on the criteria listed below on a one to five scale. Your goal is to provide ratings that help the instructor distinguish the quality of students and team projects both in comparison to other teams this semester and in comparison to teams from previous semesters.

Students: It is up to you, the student, to demonstrate to the evaluator that you meet the evaluation criteria defined below. It is not the responsibility of the evaluator to ask these questions or elicit responses from you. Be Proactive!

Rating Scale: Fractional ratings such as 2.6 are encouraged
1 = Unacceptable performance, I would fire this person if they worked for me, this defines failure.
2 = Needs improvement, clearly in the bottom 20% of students, I am disappointed in the quality.
3 = Meets but does not exceed expectations, middle 50% of students, about what I thought I'd see.
4 = Exceeds expectations, top 20% of students, I was pleasantly surprised.
5 = Outstanding, I want to hire this person to work for me, at the top of the rating scale.

Team/Project Ratings

Rating Criteria	**Rating (1-5)**
The team presented the description of the product they were trying to build. They understand the context- what it does and how it is to be used.	
The work was technically sound. I did not find any major errors.	
The team presented a system or block diagram level description of their product. I understand how all the systems work together.	
The team explained the design process. I understand why they made design decisions that resulted in meeting published specifications	
The product they demonstrated was built to professional, commercial standards. It looks really well built.	
The team presented measured specifications of their product. They described how the measurements were performed and repeat them if applicable.	
The team completed the product design and fabrication. The project is complete, meets published standards, and is safe.	

Ratings of Individual Students

Rating Criteria					
This student understood and explained the importance of their role in the project.					
The student made a meaningful contribution to the project outcomes.					
The student understands the goals and background of the project.					
The student discussed their part of the project technically, using correct terminology.					
The student's work was technically correct. They made no major errors.					
The student understood the context of the problem. They can discuss social, technical, economic, or environmental consequences of this work..					