Aligning Design to ABET: Rubrics, Portfolios, and Project Managers

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Abstract

This paper discusses on-going modifications to a two-semester capstone design sequence in electrical and computer engineering intended to both improve student learning in design and better utilize the artifacts produced by the course to meaningfully assess ABET outcomes. The first modification was to implement a more structured learning experience with well-defined design milestones that corresponded to our program's conception of the design process. The capstone course adopted a "spiral" framework of design based on the Vygotsky cycle which is drawn from socio-constructivist theories of learning. The practical implementation of this framework was supported by developing milestones teams had to successfully complete before they could move to the next phase of design. Milestones were also aligned with specific ABET outcomes and student learning was assessed on each milestone using scoring rubrics. The paper discusses the development of the milestones to address convergent and divergent aspects of design.

The second modification was to replace individual design lab books with a team archive that documented how the team's conception of design evolved over the capstone experience. As with the selection of milestones, the format of the team archive was designed to assess specific ABET (a)-(k) learning outcomes. To support a project archive that longitudinally captured evolution of each team's design on a weekly basis, team sizes were increased from 4-5 students to 6-7 students in order to add two new roles to the team: a project manager and lead engineer. The project manager served as the liaison with the client, managed the team's resources, and maintained the project archive. The lead engineer was responsible for overall system architecture and integration. These roles were supported by developing a separate grading system for these two roles; the impact of these roles on supporting the spiral conception of design is discussed. The paper discusses the impact of these modifications on student learning and the impact the changes had on providing actionable assessment for the ABET accreditation process. Documentation of team roles, the format of the archive, and scoring rubrics are discussed.

Background

Design as an activity has undergone a resurgence in undergraduate engineering programs in the last decades [1]. While engineering analysis courses focus on narrow, domain-specific knowledge, design courses emphasize application of a broad spectrum of knowledge in narrow contexts. 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, 3]. Design courses address many learning outcomes in engineering programs, but these can be classified broadly into design problems and design processes. Design process outcomes teach students the process of design while design problem outcomes emphasize application of a prior knowledge in a problem-based context, and 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. Dym, et. al. [4] point out that unlike analysis courses which use convergent thinking, design also utilizes divergent thinking. In convergent thinking many different paths converge on a single correct answer. Divergent thinking, in contrast, focuses on the manipulation of concepts to allow new directions of inquiry. Another difference between analysis and design courses is the importance of tacit knowledge in the design process [5].

There has been a great deal of work on design processes and ways to improve, manage, and teach them. Dutson et. al, reviewed the literature on capstone design courses [6] over a decade ago. Dym and co-authors [4] 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. 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" and related to the engineering discipline [7, 9], the difficulty of beginning with very open-ended problems, and choosing "modern and emerging technologies with which most of the students would have some familiarity" [8].

This paper reports the effects of three inter-related changes to a capstone design course in an electrical and computer engineering department at a predominately undergraduate university. The changes were made as part of a long-term, ongoing revision of the course to better assess student learning and improve student design abilities including supporting divergent and systems thinking as outlined in “The Engineer of 2020” [9]. The capstone design sequence consists of two courses in the senior year taken sequentially. The first, fall semester course is half the academic credit of the spring course. As with many capstone design courses, the course had undergone slow but continuous evolution over time. Changes made to the course prior to those reported here include: introducing externally sponsored projects, formalizing reporting requirements through team reports and individual work logs, and the introduction of scoring rubrics.

Design Milestones

The first modification was to implement a more structured learning experience with well-defined design milestones that corresponded to the degree program’s conception of the design process. The milestones were communicated to student teams using a Gantt chart, shown in Figure 1.

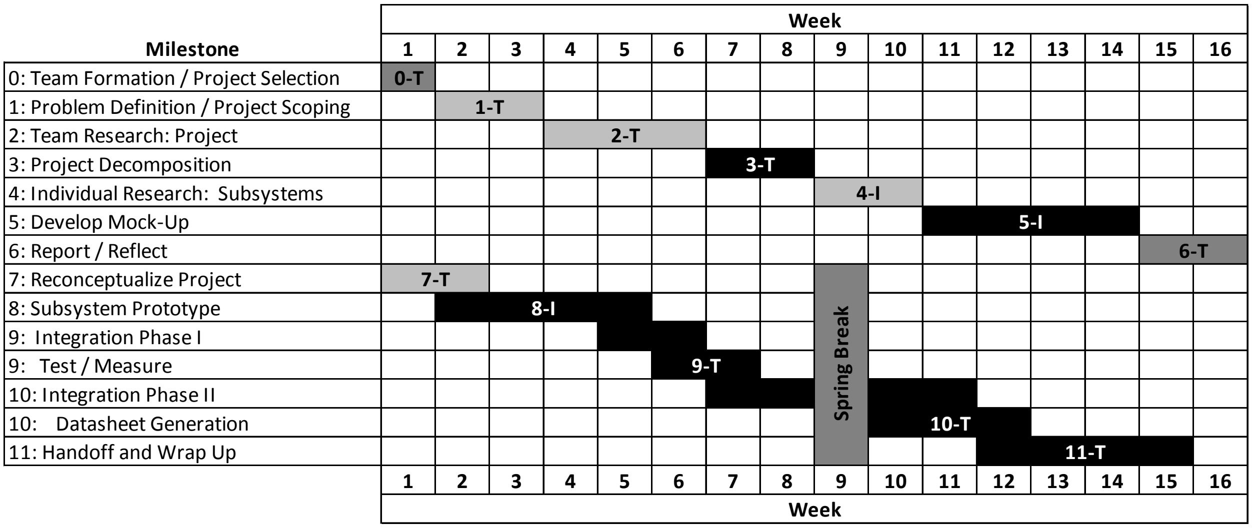

Figure 1:

Both fall and spring semesters are represented in the Gantt chart, with the fall on the top and spring semester on the bottom. The fall semester was generally designed to get students to think divergently with periods of convergence. Blocks in light grey on the Gantt chart are dedicated to divergent thinking, while those in black represent convergent thinking. Dark grey blocks cannot be classified as divergent or convergent. In the spring semester teams converge to a workable design, with the first two weeks set aside for teams that needed to think divergently in reconceptualizing their projects.

The general goal of each of the milestones was communicated to students in class at the start of the milestone period. Additionally active learning exercises were used to teach basic concepts related to each milestone. A brief description of each milestone is given below:

0) <u>Team Formation and Project Selection:</u> Teams self-selected guided by a design experience survey given in class (see appendix). The survey, a paper instrument given in class, asked students to report on prior experience in coding, fabrication, or other design-related skills (not knowledge) that had been acquired outside the curriculum; e.g. through hobbies or internships. The survey also had students report conflicted blocks of time and interest in team roles. Using the survey as a form of resume a "speed dating" exercise allowed students to compare skill sets before forming teams. Teams were also given a list of projects for external clients which had been vetted by the instructors and self-selected a project to work on.
1) <u>Problem Definition and Project Scoping:</u> In this milestone teams identified the constraints and contexts of their project as well as exploring the needs of the client. Teams presented a fifteen minute oral presentation at the end of this milestone.
2) <u>Team Research:</u> Here the team undertook research to explore previous work in this area and were specifically charged to try to expand the problem space. Since novice designers

often focus on a single pathway to a solution early in the design phase, teams had to identify and rate three viable approaches to solving the problem. Teams also established an external advisory board. The research was summarized in a written report.

3) Project Decomposition: This milestone had teams converge to a proposed solution and present it as a block diagram. The team block diagrams had to determine the necessary functions of the projects and devise a set of sub-systems that performs each necessary function. The block diagram also had to represent how the effort of the team was apportioned in a way such that each design engineer (discussed subsequently) took on responsibility for at least one of the functional components, allowing each person to become a specialist on some aspect of the overall project. Each team gave an oral presentation to explain how the block diagram addressed the functional needs of the project.
4) Individual Research: After each individual (except for the lead engineer and project manager, discussed subsequently) were assigned a functional element of the system, they performed in-depth research on the specific implementation of the block(s) they were assigned. Here the goal was to design a functional element with defined inputs and outputs. Each person was to research multiple methods to implement the functions of the block(s) they were assigned including specific components, modules, or algorithms. The milestone concluded with a short written report and individual consultation with the instructors to discuss the results of the research.
5) Feasibility Testing: During this phase of the design process individual students determined whether the approach they identified in the previous milestone was feasible through code, simulation, or a simple prototype. Students prepared a short written report and met individually with the instructors to demonstrate that their approach was feasible.
6) Report/Reflect: Each team reported on their accomplishments by comparing the current status with that at each previous milestone. The format was a narrated presentation that asked teams to reflect on the changes and place them in the context of the problem statement and client needs. Each individual was also asked to do a short written reflection that focused on their contributions to the team and their own learning during the course of the semester. This was the last milestone of the fall semester.
7) Reconceptualize Project: The goal of the first milestone of the spring semester was to permit each team to propose major changes to their project. The reflection exercise in the previous milestone was designed to elicit doubts over the period of the winter break. Changes needed to be vetted by the client, advisory board, and (if necessary) the instructors.
8) Subsystem Prototype: In the prototyping phase individuals developed functioning sub-systems and demonstrated that they worked by measuring input and output signals, data, etc. from the block, essentially performing a unit test. Each student submitted an input/output table with measurements of the inputs and outputs. While most students were

able to demonstrate a working subsystem, some students struggled on this phase of the design project.

9) Integration Phase I and Test/Measure: This milestone was performed in two phases. In the first phase the lead engineer demonstrated the system functioned correctly when all the blocks were connected together, corresponding to an integration test. A second, more formal demonstration required measured data and specifications available in a format suitable for an informal presentation. The team was asked to compare the system performance to the desired performance using detailed, quantitative metrics, and develop a well-articulated plan to improve the performance of the system.

10) Integration Phase II and Datasheet Generation: The second integration milestone also had two phases that demonstrated the project was fully functional. The lead engineer first demonstrated the system to the instructors informally to receive feedback, followed by a team demonstration of the overall functioning of the system. At this time the team presented results from a complete test protocol that shows the system met the client's specifications. Teams were responsible for developing a test protocol jointly with the client.

11) Handoff and Wrap Up: The year-long project concluded by the team taking any final actions needed to get the project ready to hand off to the client. A formal report in the form of a datasheet was prepared for the client. If the team did not demonstrate a working system in the previous milestone, they submitted a datasheet on what they had accomplished, but also were required to submit a failure report that analyzed the technical and social causes of the failure.

The rationale for creating a much more structured design course was the observation that students were often not sufficient familiar with the design process to exhibit good design habits. While students were exposed to a cornerstone design experience in their first year, it has been shown that the knowledge from such "bookend" courses does not persist for four years [10]. While expert designers move fluidly through stages of design [11], it was hypothesized the more structured format would introduce novices to elements of good design. To support learning of the various stages of design students—whether individually or in a team—would learn aspects of the design process by going through a process of social construction of design knowledge by following the Vygotsky cycle [12-14], figure 2.

In the Vygotsky cycle understanding develops through four sequential transitions between the numbered quadrants of figure 2. Briefly in quadrant one, appropriation, an individual is given information in a public, social setting then appropriates aspects for themselves. Each milestone's goals were introduced in a weekly class meeting and appropriation was supported with active learning exercises. Active learning was chosen to help to move the student from the public display and group or social realization/conception of knowledge, "This is what the class taught", to ownership of this social knowledge, "This is what I learned". The second quadrant, transformation, has the student use (internalize) what they appropriated by meeting defined goals for the milestone. It is through this internalization process that the student transitions from individual ownership (display) of knowledge in quadrant two ("This is what I learned") to developing their own personal understanding of what this knowledge means in quadrant three ("This is what I think"). The next step, publication, is designed to allow a comparison of the individual's internal conceptions of knowledge to the shared understanding of the cultural group by having the student or team publish their conceptions to experts (the instructors). This is the reporting, demonstration, or consultation described above. By public display of individual knowledge (realization) the student moves from quadrant three ("I think this true") to quadrant four ("I know this is true") by testing their individual understanding and affirming that their conceptions agree with those of expert designers. The final step, conventionalization, occurs when the individual's learning is fully integrated back into the public social domain. On the diagram they move from quadrant 4 back to quadrant 1; "I share this truth with others of my culture". Fundamental to the Vygotsky cycle is the idea of transformation both of self and of knowledge [15]. The Vygotsky cycle's emphasis on social development also addresses aspects of teamwork and individual accountability, critical to well-functioning teams [16].

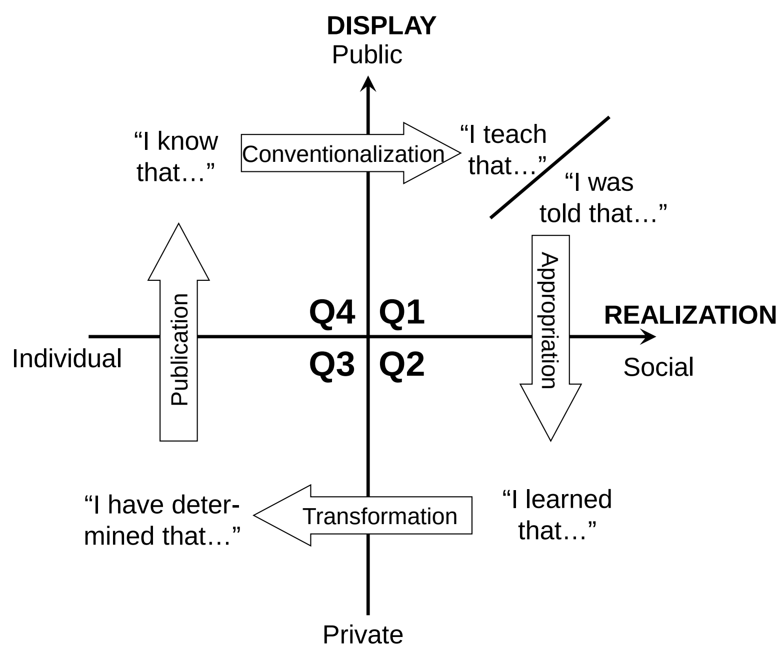

Figure 2: Four quadrant depiction of the Vygotsky cycle, the socio-constructivist model of learning used to design the capstone milestone structure.

Given that publication and conventionalization are key elements of the Vygotsky cycle the instructors chose to have formal reporting requirements for each milestone. These were typically short, a page or two, in length to capture the major outcomes from each step. The instructors were cognizant of the fact that such regular communication might be negatively perceived by students and monitored the workload during weekly project management meetings and informal conversation with students. All short communications from students were incorporated into the team's project archive (discussed subsequently).

Note that given the socio-constructivist framework, the Vygotsky cycle, and thus the design learning model adopted in the course, imply that learning occurs both individually and in a group. The course structure implicitly accounted for both of these elements with milestones designated as either team milestones or individual milestone, indicated by e.g. 1-T or 5-I in Figure 1. Scoring student work differed between individual and team milestones. Team points were earned by the entire team for passing a team milestone. The team score on the milestone served as a *base score* that was scaled by a *weighting facto*r that could range from 50% to 150% determined for each student by the instructors for each milestone. The primary influence on the weighting factor was a peer evaluation given after completion of each milestone [17]. The peer evaluation instrument included survey questions, a quantitative measure of the work performed by team members on milestone related tasks, and a means for student to comment anonymously on team members' performance. Other factors included participation, knowledge, overall attitude and professionalism. In contrast, individual milestones provided points to each student and only affected that student's grade. In practice actual grade adjustments were up to +20% and –15%, although these represented extremes. Overall instructors attempted to keep the sum of all adjustments to zero in the spirit of using the rubrics to score overall performance. Students who performed outside the ±10% range were contacted by instructors and to identify the source of either taking on too much responsibility or underperforming. The overall idea was to allow timely interventions.

The end of each milestone period shown in Figure 1 served as a deadline to complete that phase of design. Each milestone of the project was separately scored using rubrics developed for each milestone. The rubrics are attached as appendices at the end of the paper, and numbered sequentially. One significant change to the course was to move to a mastery model, similar to the curriculum at Alverno College. The rationale was that a successful project outcome requires that each stage of the design process be completed successfully. Thus students needed to receive a rubric score of 70% at each stage before they are allowed to proceed with the next stage of the project. Teams or individuals that do not score above 70% are given feedback on mistakes or areas that were not sufficiently addressed and resubmitted work once the errors were corrected. Late penalties accrued to work that was past the deadline as given by a weighting factor f:

$$f = 90\% - \sum_{n=1}^{9} 2(n-1)$$

where n is the number of days past the deadline. The score on the milestone was multiplied by the weighting factor. To encourage individuals or teams to complete the milestones ahead of the deadlines, a weighting factor greater than 100% could be earned for early work. In this case the weighting factor f, gives the percentage of the score added to the overall number of points:

$$f = \sum_{n=1}^{5} 2n \; .$$

The course was taught by two instructors, one from the electrical engineering faculty and one from computer engineering. All artifacts were scored individually using the rubrics, then the instructors then met to compare scores after all reviews had been completed. In most cases scores were in good agreement; where differences existed the instructors compared notes and arrived at a consensus scores. Given the discrete milestones for each stage of design and the use of rubrics with defined scoring categories it was natural to integrate the scoring done as part of teaching the capstone course to assessment of specific ABET outcomes. Every ABET (a)-(k) outcome—with the exception of (a) which was already over-assessed—was measured at least one point in time during the year. Some examples will serve to illustrate the process. For ABET outcome (j)—a knowledge of contemporary issues—the context and constraints subscores from the first milestone and constraints subscore from the rubric on the sixth milestone were used. Similarly for outcome (e)—an ability to identify, formulate, and solve engineering problems—the overall score from the rubric on milestone #4 was used. To measure an ability to communicate effectively—ABET outcome (g)—the subscores from the rubrics for milestones #1, #2, and #5 gave insights into performance. For individual milestones scores could be used directly. For team milestones the performance of individuals could not be directly measured. In this case the score was scaled using results from the electronic peer evaluation which returned measures of student contributions to different aspects of each milestone.

Expanding Team Roles and Archiving Design Work

The second significant modification was to expand the team size from nominally 3-4 students to 6-7 students. Along with the expansion of the team size two defined roles were created: a project manager and lead engineer. The rationale to increase the team size was based on multiple factors. One factor was the observation that in each class there was a small fraction of students who either were not sufficiently prepared to contribute in a meaningful way or who chose not to engage with the design course to the extent required for project success. On smaller teams this created a significant issue since the team did not have the resources to work around a poorly performing member and students had rarely developed the leadership skills needed to motivate underperforming members. Another factor was that the most common form of team organization and assignment of responsibilities tended to be amorphous, which caused frequent breakdown in communications between team members and between the team and instructors. How feedback was given to under- or over-performing team members was discussed previously.

The role of project manager was designed to manage all communications with the instructors, suppliers, the client, and advisory board. The project manager also coordinated the work of the other students on the team and brought potential problems to the instructor's attention early enough in a project that actions can be taken to address them. The project manager was chosen by consensus of the team and also approved by the instructors. The project manager is graded on different criteria than the rest of the team members to ensure that rather than being responsible for part of the project they had responsibility for the project as a whole; grading will be discussed subsequently. The project managers of each team met weekly with the instructor and lab director. The hardcopy of the teams' project archives (discussed subsequently) were graded and issues each team faced were discussed. Since the project manager serves as the point of contact for all instrumentation and components requests for the team, these meetings made it relatively easy to ensure communications are consistent.

A major role of the project manager is to document the team's progress on the project. The project manager was required to create a team archive that consisted of a poster size copy of the project block diagram and Gantt chart; current and past versions of the team's project reports and documentation; datasheets of all components used by the team; and copies of schematics, layouts, and project reports. The team archive also organized the individual milestone reports submitted by team members. These were kept both in hardcopy and electronic format. The project manager also kept minutes of each team, client, and advisory board meeting and collected weekly status reports from students. In past iterations of the course students were asked to keep work logs or technical notebooks that were collected intermittently and graded. There was great variation in the depth and quality of these logs, and one goal of creating the project manager role was to gain better insight into the overall evolution of the project and students' design thinking.

The second role was that of a lead engineer. The lead engineer was responsible for developing and maintaining an overall system view of the project the team was designing. The lead engineer had responsibility for developing and maintaining the team block diagram or functional decomposition, particularly in defining the interconnection protocols between functional elements and how the overall design would interface with users or outside systems. As will be discussed later, this was a difficult role for many students to take on since many lacked either the experience or training to think in systemic terms.

The remaining members of the team were given the title of design engineer. These students were primarily responsible for one or more subsystems of the overall design project, and integrating these systems into the overall project. Design engineers also picked up project fabrication skills as needed during the project integration phase. Design engineers were expected to work closely with the lead engineer to ensure their portions of the project could be integrated and the project manager to communicate issues and needs to the rest of the team.

Given the disparate responsibilities, each of the three roles had a different grading scale that reflected their responsibilities on the team. There were a total of 500 points available in the fall semester and 1000 in the spring semester as shown in the table below. Grades are assigned by the overall points earned, no curving occured. Not shown in the table are the points available for completing the weekly in-class active learning exercises, which were 10% of the overall number of points in the class. As the table indicates, the project manager receives more points for maintaining the project archives and coordinating delivery of the project to the client. The lead engineer is rewarded more for research, system integration, and functional decomposition roles than other team members. The design engineers have the heaviest point weighting on developing individual subsystems for integration into the overall project. Note, however, that points were shared to some degree across all milestone so no student sees their role as completely disconnected from other tasks.

Table #1: Relative Allotment of Points to Team Roles

	Design Milestone	Individual / Team	Design Engineer	Lead Engineer	Project Manager
Fall Semester	#1 Definition / Scoping	Team	50	50	50
	#2 Research	Team	50	75	50
	#3 Decomposition	Team	50	100	50
	#4 Research	Individual	50	25	25
	#5 Feasibility Testing	Individual	100	50	50
	#6 Defense / Report	Team	75	75	75
	#6 Reflection	Individual	50	50	50
	Project Archive	Team	25	25	100
Spirng Semester	#7 Re-Definition	Team	100	100	100
	#8 Prototype	Individual	200	100	100
	#9 Integration Phase 1	Team	150	200	100
	#10 Integration Phase 2	Team	150	250	100
	#11 Wrap Up, Hand Off	Team	150	100	200
	Design Expo	Indiv. & Team	50	50	50
	End of Year Reflection	Individual	50	50	50
	Project Archive	Team	50	50	200

Discussion and Results

As mentioned previously, the changes to the course were designed to address some of the desired attributes of engineering students that were drawn from "The Engineer of 2020" including the ability to think more systemically. The changes were also intended to avoid some of the concerns both students and faculty had about project documentation. Previously reports had been due at the end of each semester, and the role of project manager, the team project archive, and milestone structure were designed, in part, to distribute project documentation over the lifetime of the project. By adopting a more structured design timeline, it was possible to incorporate two iterations of system integration; iteration is a key element of design [4].

To understand the effect of the changes on student learning, student performance on rubric-scored artifacts, feedback from the project manager meetings, and individual student demonstrations, as well as student comments on individual reflections were analyzed. Given the wide disparity of projects and the fact that it was not possible to easily undertake a rigorous pre-post experimental design, the results are somewhat anecdotal. However the goal of this work is more exploratory in nature, and the overall results gave promise that integrating milestones and defined roles had, to some extent, the desired impact.

One initial concern in setting up a series of structured milestones with reporting requirements at each milestone was that students would perceive it as too little designing and too much writing. While individual written reflections did indicate a few students saw this as a concern, overall there were few concerns or comments and students reported value in regular small reports. In comparing student performance across the milestones, the largest area of concern was functional decomposition. There was a wide range of performance from the teams, and no team showed the desired level of expertise . Although at this time there is too little data to draw solid conclusions, poor performance generally stemmed from teams' inability to develop a functional system model for their project. This may have been related, in part, to the abilities, of lack thereof, of the lead engineer. The second area where scores varied widely was on individual research. A small but significant fraction of students did not perform satisfactorily on the research, and had to delay the start of the feasibility testing phase to demonstrate competence. Some of the reasons students self-reported for performing poorly on the research milestone were that they did not spend sufficient time on research, started late, or that their aspect of the project was not adequately defined.

Overall the structure of milestones that focused on divergent thinking, see Figure 1, early in the design sequence was moderately successful in keeping students from converging too rapidly on a single solution pathway. Although students did not seem to seriously consider contexts and constraints early in the fall course, they self-reported increasing value in understanding these aspects of design by the end of the semester. There were relatively few complaints from students about a slow pace and not getting to fabricate hardware or code software earlier in the course. One issue that affected a small number of students was the competency based model used in the milestones. Since the team or individual students had to pass a milestone with a rubric-based score of 70 or above (corresponding to between meets and below expectations), several low performing students were delayed on consecutive milestones.

In implementing three defined roles—design engineer, lead engineer, and project manager—the instructors anticipated concerns from students that the grading system was unfair or that work was not assigned fairly. These concerns did not materialize in any meeting with the project managers or individual consultations with the students. Open-ended feedback on student peer evaluation indicated that when work was perceived as unfairly distributed it was seen as arising because the team under- or over-estimated the difficulty of specific functional elements of the system. There were few concerns that the project manager had an easier role since it was non-technical; most students commented that having someone to manage the project and coordinate reporting issues and meetings was beneficial. The instructors found that the weekly meeting with project managers offered a valuable opportunity both to understand issues within the teams and also inform the team about concerns and issues.

As mentioned previously, the most problematic role was that of the lead engineer. Students generally were not adequately prepared for the responsibilities and few students were able to think in terms of systems. The structure of the milestones used the block diagram as a central anchor in organizing work so in cases the lead engineer was unclear on system organization the entire team was affected. In future iterations of the course the instructors are considering having additional educational resources on system design principles or weekly meetings to try to address these issues. There were some initial concerns that assigning the task of systems thinking to a defined person would cause other students to consider the importance of this factor of design less than they would otherwise. Observations were that this may have been true early in the design process when students focused on their blocks, but these concerns were abated later when teams had to integrate functional components into a working system. Several students ran into difficulties by choosing a solution for their block that did not address systemic needs or could not be well integrated. After these experiences teams adjusted their processes to ensure that all students focused on system requirements.

The third element was having each project manager keep a comprehensive archive of the team progress. The intent of the archive was to document evolution of the design. The instructors provided each project manager detailed instructions on maintaining the archive, which was graded weekly. While it took some time to communicate expectations, overall the archive did document the evolution of the design and team organization. There was a significant amount of experimentation by the project managers on how to get team members to provide consistent, useful status reports. Some project managers sought suggestions from their advisory boards, or sought input from extended family members who worked in engineering firms.

The project archive, by creating a central resource for Gantt charts, block diagrams, team minutes, and milestone reports from individual students provided a panoramic view of the project. From this, in conjunction with the peer evaluation data available only to instructors, it is possible to build up a composite view of individual student contributions to team milestones. These are, however, only proxies to individual performance. The individually scored rubrics for some milestones serve as the best indicators.

Overall the three changes to the capstone course—structured milestones, defined roles with different grading criteria, and distributing the reporting function—were successful. In an end-of-semester reflection in the first, fall course students were asked to conclude a written reflection exercise of which one set of questions was about how professional the environment was. The general consensus, both from students who had internships in industry and those who did not, was that the course succeeded in creating a professional environment. This is an important element since research shows that students often dissociate academic experiences from what they see as "real world" engineering [18]. From the perspective of the instructors, the regular milestone, chance to meet with project managers weekly and individual milestones made it easier to track the progress of individual students.

In the next iteration of the course the research milestone will be changed to encourage the team, particularly the lead engineer, to develop a better high level overview of their project when conducting research. Many teams got "down in the weeds" and researched details of specific solutions rather than comparing a variety of solution pathways in terms of the broader context and constraints of the problem. A second issue is that the feasibility testing milestone was communicated to students as an opportunity to experiment, and many students were unable to make judgments about whether to proceed with their approach or change direction. It was anecdotally observed that the act of making a choice was difficult for students, and choices were often made on issues not related to the relevant context or constraints of the project. In a future iteration of the course there will be enhanced focus on feasibility testing and making judgments.

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Interest and Experience Survey

What times are you not available to meet with other team members?

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Morning							
Afternoon							
Evening							

Check the boxes if you feel you have relevant experience in this area you can contribute to your design team that is NOT part of the required curriculum at Bucknell:

	Electronic design or simulation
	Electronic fabrication such as soldering or PCB design
	High level programming languages (C, Python, etc.)
	Programming microcontrollers
	Experience with cabling or wiring
	Project management or leadership experience
	Machining, 3D printing or other fabrication
	CAD tools or other simulation software (list):
	Other Relevant Experience:

Check the boxes for project roles you would be interested in:

	Design Engineer: responsible for one or more subsystems, works closely with the lead engineer to ensure their portions of the project can be integrated into the overall project.
	Lead Engineer: ensures the overall system functions, makes sure the various sub-systems meet specification and can be integrated into a working whole.
	Project Manager: ensures the project stays on time and under budget, meets regularly with upper management (faculty) and request additional help or resources, ensures the project is properly documented, and maintains team resources. All communication and request go through the project manager.

Below list the top five projects you would be interested in working on:

Appendix: Milestone #1 Project Scoping and Definition Scoring Rubric

	Unacceptable	Below Expectations	Meets Expectations	Exceeds Expectations
Solution Definition	• Solution not defined OR • Solution definition does not consider needs.	• Solution or problem is little changed with no explanation. • Definition is vague. • Solution somewhat related to needs.	• Changes to problem and solution are explained. • Definition is wordy or not compelling • Solution somewhat related to needs.	• Focuses on solution more than problem. • Solution clarified by redefining problem. • Definition is clear, short, and compelling. • Solution definition clearly related to needs.
Needs Statement	• No needs statement. • Needs not verified by client. • No TRL	• Needs not prioritized. • Needs are incomplete. • Needs statement was discussed with client. • No justification for TRL	• Needs are organized hierarchically. • Needs are mostly complete. • Needs statement is verified by client. • Appropriate Technology Readiness Level has been identified.	• Needs hierarchy is sensible and complete. • Discusses process by which needs were analyzed, refined, and prioritized. • Needs statement is verified by client. • Appropriate TRL identified.
Displays Divergent Thinking	• No evidence of questioning the problem statement or divergent thinking. • Process did not impact problem or needs.	• Questioning superficial or merely technical. • Has difficulty identifying ambiguities or uncertainties. • Brainstorming not well documented. • Little evidence of how problem space changed.	• Questioning has been done but process is not clear. • Identifies ambiguities or uncertainties. • Lists the ideas generated during brainstorming. • Some evidence that problem space changed.	• Describes the *process* of questioning the problem/solution. • Identifies ambiguities or uncertainties. • Organizes the spectrum of ideas generated during brainstorming. • Discusses how problem space changed as a result of questioning.
Understands User/Client	• No solid information on client presented. • No perspective of client.	• Incomplete understanding of client. • Fails to conceive of other clients. • Little research on client.	• Partial understanding of client. • Other clients acknowledged. • Some research on client.	• Good understanding of client. • Has identified other possible clients. • Presents sound research on client.
Explores Larger Contexts	• Fails to place the project in larger contexts, narrow technical view of project.	• Addresses *few* relevant contexts or emphasizes irrelevant contexts.	• Addresses *most of* the relevant contexts.	• Addresses all *relevant* contexts including: Economic, Social/Cultural, Political/Regulatory, Ethical, Health/Safety, Manufacturability, Sustainability/Environmental, Global, Legal/IP
Identifies Constraints	• Substantially fails to identify reasonable constraints.	• Identifies valid constraints in *few* contexts. • Constraints seem artificial or manufactured.	• Identifies valid constraints in *mos*t contexts. • Constraints not clearly related to problem definition.	• Identifies valid constraints in *all* of the above contexts. • Discusses how constraints affected problem definition.
Draws Upon Team's Diverse Perspectives	• Project seems to be the work of one or two persons.	• Fails to present individual conceptions of project. • Process used to develop team problem definition unclear.	• Some, but not all, team members conceptions presented. • Discusses process used to develop team problem definition.	• Presents *each* team member's conception of problem. • Used effective process to develop team problem definition.
Presentation Quality	• The team failed to answer basic technical questions. • The presentation failed to make the points the team needed to.	• The team correctly answered *some* technical questions. • The presentation was not well organized. • The team failed to use technical language or used it incorrectly.	• The team correctly answered *most* technical questions. • The presentation was organized but hard to follow at times. • The team mixed technical and vernacular language.	• The team addressed *all* technical concerns. • The presentation was well organized and conveyed a story. • The team used technical language correctly.

Appendix: Milestone #2 Team Research Report Scoring Rubric

	Unacceptable	Below Expectations	Meets Expectations	Exceeds Expectations
Understanding of Problem	• Problem not identified. • Not clear if understanding changed. • Little mention of constraints and contexts, or irrelevant. • Value of advisory board not evident.	• Problem statement vague. • Change in understanding minor. • Constraints and contexts present but not fully relevant to problem. • Advisory board discussed.	• Problem statement is clear. • How team's understanding changed is stated. • Constraints and contexts relevant, but lack detail. • Feedback from advisory board evident.	• Problem statement is compelling. • Evolution of team's understanding of problem is clearly outlined. • All constraints and contexts are relevant and clearly stated with quantities if possible. • Advisory board clearly added to team's understanding
Research Expanded Problem Space	• Approaches, techniques, or tools missing or wrong. • How research expanded problem space not evident. • Research from team members often inaccurate or irrelevant. • Significant research missing.	• Approaches, techniques, or tools hit and miss. May be irrelevant • Unclear how research expanded problem space. • Research has some errors but is mostly correct. Research somewhat incomplete or irrelevant.	• Approaches, techniques, or tools present but inconsistently described. • Some examples of how research expanded problem space, lack of detail. • Research is mostly correct and complete, some research may be irrelevant.	• Research identified new approaches, techniques, or tools which are listed and described. • Team provides multiple, detailed examples of how research expanded problem space. • Research is substantively correct. • Research is substantively complete. • Research is relevant to the problem.
Identifies Possible Approaches	• Multiple approaches not considered. • Merits and disadvantages not stated. • No future research . • Context, constraints, needs not mentioned. • Significant lack of details or fundamentally incorrect.	• Three approaches described, one reasonable. • Merits and disadvantages unclear or partially incorrect. • Future research not clear. • Only passing mention of context, constraints, or needs. • Lack of details makes approaches questionable.	• Three approaches described, two reasonable. • Merits and disadvantages of each stated. • Identifies areas of future research. • Merits and disadvantages related to context, constraints, or needs. • Discussion vague in places.	• Three or more reasonable approaches are described. • Merits and disadvantages of each are compared to others. • Identifies specific topics that need more research. • Merits and disadvantages are tied back to context, constraints, or needs. • Discussion is specific and detailed.
High Level Understanding & Insight	• Lack of understanding. Ignorance risks team's project or poses safety hazard. • Ideal outcome not clear. • No overall function of system.	• Ideal outcome is present but unclear. • Overall function of system lacking in correctness or detail. • Section gets down "in the weeds".	• Ideal outcome is reasonable. • Overall function of system is described. • Section has some implementation detail.	• Ideal outcome is listed, relevant, and detailed. • Overall function of system is well described and at a high level. • Section is free from implementation detail.
Documentation & Bibliography	• Citations are few and incomplete. • Most sources are clearly invalid. • Bibliography missing.	• Citations few and incomplete. • Serious questions about the validity of sources. • Bibliography allows sources to be found but does not conform to IEEE.	• Most citations in the manuscript. • A few sources of information have questionable validity. • Bibliography mostly conforms to IEEE formats.	• Sources cited throughout the body of the manuscript. • Valid sources of information used. • Bibliography conforms to IEEE formats.
Writing Quality	• Most sections are unclear • Verbose, blithering • Not suitable for technical audience. • Failure to use appropriate technical terminology.	• Some sections are unclear • Runs-on in several areas • Not suitable for technical audience. • Technical terminology not consistent and sometimes incorrect.	• Clear • Could be more concise • Meets needs of technical audience. • Technical terminology not consistent.	• Clear • Concise • Meets needs of technical audience. • Technical terminology used consistently and accurately.

Appendix: Milestone #3 Block Diagram Scoring Rubric

	Unacceptable	Below Expectations	Meets Expectations	Exceeds Expectations
Complete & Technically Feasible	• Block diagram does not adequately represent the functions of the system. • System as represented is technically infeasible.	• Block diagram missing several significant necessary system needs or functions. • Doubt as to technical feasibility of some blocks.	• Block diagram represents most necessary system needs or functions. • Decomposition is technically feasible- it can be built.	• Block diagram completely represents necessary system needs or functions. • Decomposition is technically feasible- it can be built.
Reasonable Decomposition	• Many blocks have functional overlap. • Team did not distinguish hardware and software blocks. • Functions of some blocks are missing or wrong. • Enough necessary functions were missing that design is questionable.	• Some blocks have functional overlap. • Considerable overlap of hardware and software blocks. • Functions of many blocks are vague. • Most necessary functions included.	• Each block serves a separate function with little overlap. • Some overlap of hardware and software blocks. • Functions of some blocks are vague. • All necessary functions included.	• Each block serves a separate function with no overlap. • Hardware and software blocks were represented correctly. • The function of each block was accurately described. • All necessary functions included.
Sufficiently Detailed	• The low level of detail indicates team does not understand how to decompose project. • Notation was sufficiently inconsistent that the design could not be followed..	• The level of detail was not sufficient to describe many elements of system. • The number of significant details missing led to lack of confidence in feasibility of this design. • Notation was understandable but not consistent.	• The level of detail was sufficient to mostly describe system operation. • While some details were missing/wrong, there is reasonable confidence design will converge. • Notation was generally consistent.	• The level of detail fully describes system operation. • Diagram is detailed enough that there is high confidence team can complete design. • Consistent, common standards were used in creating/labeling blocks
Work Fairly Assigned	• Team failed to adequately assess difficulty of blocks. • Workload was not addressed.	• Team had difficulty assessing difficulty of blocks. • Workload was not fairly distributed among team (including PM and LE).	• Relative difficulty of most blocks is correct • Workload reasonably distributed among team (including PM and LE).	• Relative difficulty of blocks was accurately determined • Workload reasonably distributed among team (including PM and LE).
Internal Interfacing	• A sufficient number of interconnections between blocks are missing that design is questionable. • I/O of Level 0 and Level 1 diagrams do not match. • Internal I/O table fundamentally incomplete.	• A large number of interconnections between blocks are missing. • I/O of Level 0 and Level 1 diagrams have some mismatch. • Internal I/O table has some missing information.	• Some interconnections between blocks are missing. • I/O of Level 0 and Level 1 diagrams match. • Internal I/O table has some missing information.	• Interconnections between blocks are complete. • I/O of Level 0 and Level 1 diagrams match. • Internal I/O table is complete
External Interfacing	• Level 0 block diagram does not adequately represent system. • I/O table fundamentally incomplete.	• Level 0 block diagram misses some major input/output of system. • I/O table significantly lacking information.	• Level 0 block diagram captures most input/output of system. • I/O table has some minor missing information.	• Level 0 block diagram captures all I/O. • Table of I/O is complete.

Appendix: Milestone #4 Individual Research Scoring Rubric

Rating	Well Researched	Engineering Judgment	Functional Decomposition	Understanding
Exceeds Expectations	• Research is complete and convincing. • Valid sources of information used. • Resources clearly related to project.	• Knows which parts of project are constrained and which are open to design. • Chooses best approach from multiple possibilities based on technical reasons.	• Block diagram richly detailed • The function of each block is correctly described. • Inputs and outputs are understood, complete and correct. • Fulfills all necessary functions.	• Thorough understanding of the design • Shows insight from research. • Recognizes areas of uncertainty and potential pitfalls
Meets Expectations	• Research is sufficient but not complete. • Some question about sources of information. • Resources mostly related to project, some guesswork.	• Some lack of clarity on freedom of choice vs. constraints. • Multiple approaches considered. • Judgments based on effort or knowledge rather than technical reasons.	• Block diagram sufficiently detailed • The function of each block was described but some lack of clarity. • Inputs and outputs mostly understood, complete, and correct. • Fulfills necessary functions, some uncertainty as to implementation.	• Understands their design enough to complete but not improve work. • Few gaps in knowledge.
Below Expectations	• Research is spotty or incomplete. • Serious questions about the validity of sources. • Requested resources questionable.	• Little understanding of constraints vs. choices available to them. • Multiple approaches considered. • No valid basis for choosing one design over another.	• Block diagram lacks some needed detail. • The function of each block not clearly described. • Some inputs and outputs not represented or well understood. • Most functionality is present with considerable uncertainty as to implementation.	• Does not fully understand how their design works. • Significant gaps of knowledge.
Not acceptable	• Research not done, incorrect, or incomplete. • No list of resources or list not valid.	• Multiple approaches not considered.	• Block diagram too vague or incomplete. • The function of each block not described or understood. • Major misunderstanding or misrepresentation of inputs and outputs. • Unclear how or whether the subsystem will function.	• Fundamental lack of understanding. • Ignorance risks team's project or poses safety hazard.

Milestone #5 Feasibility Testing Scoring Rubric

	Unacceptable	Below Expectations	Meets Expectations	Exceeds Expectations
Presents Evidence of Accomplishment?	Little evidence of accomplishment **OR** incorrect evidence, OR evidence unrelated to block	Presents some evidence of accomplishment (demonstration, model, etc.) **AND** evidence is mostly correct **AND** work related to function of their block(s).	Presents sufficient evidence of accomplishment **AND** evidence is correct **AND** work related to function of their block(s).	Presents concrete evidence of accomplishment (demonstration, model, etc.) **AND** evidence is correct **AND** work clearly demonstrates function of their block(s).
Demonstrates Understanding of Their Work?	Fundamental lack of understanding **OR** fails to recognize risk to team's project or safety hazard **OR** cannot answer simple questions.	Does not fully understand how their design works **OR** significant gaps of knowledge **OR** unable to address many questions	Understands their design enough to complete but not improve work **AND** able to answer most questions.	Thorough understanding of the design **AND** shows insight from work done to date **AND** able to answer technical questions.
Prepared for Next Phase of Design?	Approach infeasible or impractical **OR** little evidence alternative approaches were considered **OR** cannot place their work in context of the overall system.	Their approach to build a prototype has some weaknesses they don't address **OR** not clear how alternate approaches were eliminated **OR** not clear on function of their block(s) in context of overall project.	Discusses a feasible approach to build a prototype in next phase **AND** work clarified less valuable approaches **AND** frames their work in context of overall project.	Discusses a proposed approach to a prototype in next design phase that seems optimal **AND** work eliminated invalid approaches **AND** frames their work in context of overall project.
Has Correctly Documented Effort?	Little or no documentation.	Documentation is significantly incomplete **OR** format not appropriate **OR** documentation not accessible to team.	Work is mostly documented **AND** format o.k. but not ideal **AND** documentation accessible to team.	Documentation is complete and correct **AND** presented in suitable technical format **AND** documentation is available to entire team.

Appendix: Milestone #6 Narrated Presentation Scoring Rubric

	Unacceptable	Below Expectations	Meets Expectations	Exceeds Expectations
Constraints	• Fails to compare current and past constraints. • Most constraints are not relevant or incomplete. • Project divorced from constraints.	• Only minimal comparison of current and past constraints. • Some constraints are not relevant or incomplete. • Constraints not related to evolution of the project.	• Lists both current constraints and those from Milestone #1. • Current constraints are relevant but not complete. • Mentions how constraints affected evolution of the project.	• Lists both current constraints and those from Milestone #1. • Current constraints are both relevant & complete. • Explains how constraints affected evolution of the project.
Approach	• No discussion of how approach changed. • Changes in the team's approach are random or ad hoc.	• Minimal comparison of changes to approach. • Provides few reasons to support changes in the team's approach.	• Compares approach at Milestone #2 to current approach. • Provides some reasons to support changes in the team's approach.	• Compares approach at Milestone #2 to current approach. • Provides sound reasons why changes in the team's approach to the project were made.
Block Diagram Evolution	• Block diagram evolution not discussed or changes are not clear. • Current diagram missing critical detail, incorrect, or incomplete.	• Block diagram evolution presented as before and after. • Changes to diagram unclear or not well explained. • Current diagram lacks detail, not fully correct, complete, or hard to read.	• Block diagram evolution presented in multiple frames. • Changes to diagram stated, not explained. • Current diagram is mostly detailed, correct, complete, readable.	• Block diagram evolution presented in multiple frames. • Explains reasons for changes to diagram in context of project. • Current diagram is detailed, correct, complete, readable.
Individual Roles	• Technical responsibilities not mentioned. • Individual unclear on role on team. • Work on block not present or incomplete.	• Technical responsibilities of all team members stated but not described. • Not clear how individual provides other value to team. • Evolution of blocks unclear.	• Technical responsibilities of all team members described. • Value to team in other capacities evident. • Only describes changes to block(s).	• Technical responsibilities of all team members described. • Explains value of other (non-block) contributions to team. • Explains why changes to block(s) were made.
Team Development	• Gantt chart not useful tool, too general, or missing. • Fails to define team roles and responsibilities. • Current team status unclear or vague.	• Gantt chart changes, but not increased usefulness. • States roles and responsibilities but fails to describe them. • Current team status mentioned but lack insight.	• Evolution of Gantt chart shows increased detail but not understanding. • Explains what roles and responsibilities are with some rationale. • Discusses current team status in a way that does not suggest future improvements.	• Evolution of Gantt chart shows increased understanding of project and informs actions. • Explains how and why roles and responsibilities were assigned. • Discusses current team status and suggests changes to improve performance.
Lessons Learned	Fails to mention what was learned.	Lessons learned are: • focused on self or team • not actionable • not informative.	Lessons learned are: • related to specifics of project • actionable • inform self or team.	Lessons learned are: • related to design • actionable • inform others.
Presentation Quality	• Presentation detracts from message. • Lack of animation or detracts from presentation • Audio unacceptably bad.	• Disjointed, hard to follow, lacks professional appearance • Animation present but not well used, • Audio negative impacts quality.	• Acceptably organized, appearance could be better • Animation used, sometimes distracting • Audio clear and understandable, with some variation in volume and quality	• Visually well organized and professional • Effective use of animation • Audio clear and understandable

Appendix: Milestone #8 Prototype Demonstration Scoring Rubric

	Unacceptable	Below Expectations	Meets Expectations	Exceeds Expectations
Diagrams, flowcharts, and/or pseudocode				
At scale of a Level 1 Block diagram	Not present	Understandable but over- or under-detailed.	Acceptable. Mostly accurate and at correct scale.	Correct scale and accurately represents block.
Clear and detailed	Unclear	Mostly qualitative	Mostly quantitative, misses some detail	Quantitative and detailed
Matches demonstrated block	Fails to match	Significant misalignment	Some misalignment	Complete overlap
Inputs, outputs, test/debug points labeled.	Labels missing or wrong	Several are missing on diagram or lack detail.	Present but lacks some detail.	Complete, accurate, and student demonstrates they are in prototype or code
Inputs				
Desired inputs are quantified and present	Representation and prototype do not match.	Significant mismatch between prototype and representation	Prototype mainly matches representation.	Prototype completely matches representation.
Inputs are measured.	Significant number not demonstrated.	Test protocol incomplete or range unreasonable.	Covers most conditions and is realistic.	Convincing and complete demonstration of conditions
Provides data in form of tables or graphs.	Data not provided or not readable	Significantly incomplete, poorly formatted, or unclear.	Mostly correct, some labels, units, etc, not clear. Not fully complete.	Complete, well documented, provides useful evidence, correct.
Outputs				
Outputs from block diagram listed.	Representation and prototype do not match.	Significant mismatch between prototype and representation	Prototype mainly matches representation.	Prototype completely matches representation.
Outputs are measured.	Significant number not demonstrated.	Test protocol incomplete or range unreasonable.	Covers most conditions and is realistic.	Convincing and complete demonstration of conditions
Provides data in form of tables or graphs.	Data not provided or not readable	Significantly incomplete, poorly formatted, or unclear.	Mostly correct, some labels, units, etc, not clear. Not fully complete.	Complete, well documented, provides useful evidence, correct.
Test points and Debugging				
Are these useful for system debugging?	Not present, not discussed, not used.	Present, but little evidence of usefulness.	Somewhat thought out, not fully used.	Carefully thought out, helped understand function.
Evidence of measured values, states, software execution times?	Little to no evidence.	Poorly organized, not well documented.	Documented but not clear without explanation.	Documented in lab book or notes, clear, readable.
Overall: System Works				
Does the system function as it is supposed to?	No	Partially	Mostly	Fully
Does the student have a clear path to correct/improve this block?	No.	Some evidence, but plans not well understood or articulated.	There is enough evidence and understanding that progress will be made.	Yes.
Is the student knowledgeable about their project?	Significant gaps of knowledge.	Somewhat, they should have been more knowledgeable.	Mostly, some areas still not understood.	Yes, able to answer detailed question.

Appendix: Milestone #9 System Integration I & Demonstration Scoring Rubric

	Unacceptable	Below Expectations	Meets Expectations	Exceeds Expectations
Functionality	• Major parts of system incorrect or incomplete. • Workable plan not in place.	• System works sufficiently to demonstrate function • Some functions not complete but has concrete plans to improve.	• System generally works, some parts not working properly	• System works.
Inputs & Outputs	• Some system I/O missing Errors in measurements make results invalid.	• All I/O present • Some inputs and outputs are not measured.	• All I/O present Inputs and outputs are measured but not well or reliably	• All system inputs and outputs are measured and demonstrated.
Separation of Subsystems	• No separation of blocks, cannot isolate parts of system.	• Some blocks are merged • Blocks not separated, but some parts of system can still be isolated.	• Blocks are separate can be isolated, but not clearly identifiable	• Blocks are separate and identifiable
Understanding	• Lack of understanding. • Ignorance gives high probability of failure or poses safety hazard.	• A few significant lapses of the understanding of the project.	• Team understands overall design enough to complete but not improve work.	• Thorough understanding of the design and pathway to improve evident. measurement process.
External Communication	• Unable to communicate with outside devices. No workable plan to fix.	• Unable to communicate with outside devices. Plan to fix in place.	• Communication with outside devices sometimes sporadic.	• Communication with outside devices works as supposed to.
Test and Measurement	• Little evidence of measurements. • Test protocol not evident or invalid. • Does not understand measurement process.	• Some needed measurements not made. • Test protocol is faulty or incomplete. • Does not understand measurement process enough to ensure results are valid.	• Most measurements are documented. • Test protocol is evident and reasonable. • Understands measurement process enough to make judgments.	• Documentation through measurements presented. • Test protocol accurate and complete. • Understands measurement process enough to ensure results are valid.
Individual Awareness & Engagement	• Speaks in general terms, details or examples are missing or wrong. No sense of ownership.	• Evidence given, but not consistently. Somewhat engaged in the problem.	• Shows ownership and understanding of their portion of project.	• Provides specific examples with details, person is clearly engaged.

Appendix: Milestone #10 System Integration II & Demonstration Scoring Rubric

	Unacceptable	Below Expectations	Meets Expectations	Exceeds Expectations
Demonstrates Functionality	• Major parts of system incorrect or incomplete.	• System works sufficiently for client needs, some lack of functionality. • Little improvement in system function.	• System works. • Some improvement.	• System works fully and completely Team clearly demonstrates improvement in this iteration.
Inputs & Outputs	• Some system I/O missing • Errors in measurements make results invalid.	• All I/O present- some lack of functionality. • Some inputs and outputs are not measured.	• IO functional. • Inputs and outputs are measured but not well or reliably	• All system inputs and outputs are measured and demonstrated. • IO suitable to project needs.
Understanding	• Lack of understanding. • Ignorance gives high probability of failure or poses safety hazard.	• Does not understand design process enough to ensure results are valid.	• Team understands design process enough but some decisions not well supported.	• Thorough understanding of the entire design process and able to justify design decisions.
Quality & Robustness	• Poorly built, designed, or assembled. Will break on normal use.	• System does not follow good design practices, not well fabricated, will not withstand long-term normal use.	• Design practices followed, system is built to acceptable standards, should withstand normal use.	• Design practices followed, system is professionally fabricated and able to withstand normal use.
Integration	• Does not communicate with external devices to extent needed.	• Communication is sporadic. • Project is not well integrated with external devices/users.	• System communicates with external devices/users to extent necessary. • Integration functional but lacks finesse.	• System is fully integrated with external devices/users and communicates with them. • Shows knowledge of human factors and client needs.
Product Testing	• Little evidence of measurements. • Test protocol not evident or invalid. • Does not understand measurement process.	• Some needed measurements not made. • Test protocol is faulty or incomplete. • Data does not fully support claims / capabilities of system.	• Most measurements are documented. • Test protocol is evident and reasonable. • Data provides evidence of capabilities of system.	• Documentation through measurements presented. • Test protocols accurate and complete. • Data clearly demonstrates capabilities of system.
Individual Awareness & Engagement	• Speaks in general terms, details or examples are missing or wrong. No sense of ownership.	• Evidence given, but not consistently. Somewhat engaged in the problem.	• Shows ownership and understanding of their portion of project.	• Provides specific examples with details, person is clearly engaged.