Reflection and Metacognition in Capstone Design

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Abstract

Reflection is a valuable skill that is not immediately familiar to many of our students. Our faculty team has introduced systematic reflection in a two-semester multidisciplinary engineering design course at the United States Military Academy at West Point. A course goal is to produce engineers competent in designing with current technologies who are able to anticipate and to respond to change. Because a key component of the course has always been the assessment of the design against the requirements, we chose to augment the design process with multiple opportunities for reflection.

This year's course consists of 18 capstone project teams with a total of 112 students. The teams range from triples of computing majors to over a dozen students from six different majors and four different departments. Reflection periods occur several times throughout the academic year, not just at the end. Some reflection consists of periods of silence spent individually. Other reflection takes place in the context of lively group discussions. These techniques were developed by the authors, a team of three faculty who have co-taught this course for several years and who wanted our students to pursue deeper, more creative solutions to problems, to form more cohesive teams, to be more deliberate in their decision-making and to avoid the last-minute rush to completion right before the final demonstrations. These reflection exercises have been introduced over the last three years and have resulted in a marked improvement in the pace and quality of student work. Students were more engaged with the project. They developed more insightful or creative designs, formulated better relationships within their team, and demonstrated a deeper understanding of their product and how it satisfies customer requirements.

Introduction

"The unexamined life is not worth living [1]." From Socrates to modern-day mindfulness gurus, there is a recognition that we do better work and are better and happier people if we regularly step back and reflect. And for students from elementary through university level, studies have shown how metacognition improves learning. Shapiro posits that contemplation in an elementary and middle school setting can improve children's social and emotional skills [2]. At the undergraduate level, Bernadez et al. have found software engineering students to be slightly more efficient in developing conceptual models after four weeks of mindfulness training [3]. Rieken et al. have found positive correlations between mindfulness and innovation self-efficacy in undergraduate engineering students [4]. In the business world, Goleman shows that mindfulness results in "stronger focus, staying calmer under stress, better memory, and good corporate citizenship [5]." And in the military, mindfulness has attracted attention as a way to "to heal trauma-stressed veterans, make command decisions and help soldiers in chaotic battles [6]."

But we live in a society that tends to favor activity over reflection. From laptop to tablet to smart phone to smart watch, technology provides ubiquitous means for distraction and opportunities for multitasking. Our students, who have grown up in the digital age, believe this frenetic life pace to be normal and have consequently not developed skills for sustained reflection or contemplation. Sharon Daloz Parks observes that many of today's university students have a lifestyle that "has no room" for pondering deep questions [7]. She advocates for universities to create environments where students can develop critical thinking skills that will enable them to make sense, not just of their academic discipline, but of their larger role in society and purpose in life [7].

To help our students develop greater capacity for reflection and mindfulness, we have introduced several events into our capstone design course to require students to reflect on their experience, including behaviors contributing to the design and their interpersonal exchanges with their peers, faculty and clients. Some of the reflection exercises we describe were introduced two years ago, with the remainder added last year. All remain in use this year.

The need for reflection has also been recognized at the institutional level as our academic schedule has been modified to include ten "reflection days" on Wednesdays throughout each semester. No classes meet on a "reflection day." Instead, students are encouraged to work on projects, papers, or other academic exercises that require extended periods of deep and sustained thought.

The next section describes our capstone design course, followed by an explanation of each reflection experience in the context of the design process. We then present a quantitative and qualitative summary of the results of these changes. Our conclusions are offered in the final section. Appendices contain rubrics of the reflection exercises.

Capstone Design Course Structure

The authors have designed and offered a two-semester multidisciplinary engineering design course within the Electrical Engineering and Computer Science (EECS) Department at West Point. EECS includes three ABET-accredited majors: Electrical Engineering, Computer Science and Information Technology. Three years ago we began an evolution of the three disciplinary-specific capstone courses (CS401/402, EE401/402 and IT401/402) into a single multidisciplinary course (XE401/402). That evolution was completed this academic year. The course is mandatory for all seniors in our department and often includes students from other departments who participate in our projects.

This year there are 18 project teams comprising a total of 112 students. The teams have an average of seven students from three majors and two departments. The smallest project team consists of three students. The largest team has 14 students. The most diverse team has 12 students from six majors and four departments. Most of the students are majoring in ABET-accredited engineering or computing programs, but two teams constructing augmented-reality historical simulations include students majoring in History and Geospatial Information Science. Most projects have external sponsors - typically a government agency that appoints a senior engineer to serve as the customer. These customers provide project ideas, input on scope and requirements, and financial support for equipment and travel.

We have formulated an iterative “agile-waterfall” design process combining the traditional “waterfall” design practice found in engineering with agile methodology common to software design [8], [9]. This process encourages rapid prototyping and short term goal-setting (through a series of “sprints”) and requires our students to assess their design against specifications to determine whether the design is progressing in a satisfactory manner. Design reviews are built into the process to force this periodic assessment. However, the design process is product-focused while our undergraduate capstone design course is student-focused. Our goal is to produce more than just a working prototype; we strive to produce graduates competent in current technologies who are able to grow and develop in response to (and in anticipation of) the rapid pace of change. Therefore, we augmented our design process with multiple opportunities for reflection.

Reflection Experiences

An Introductory Mini-Project: Autonomous Ground Vehicles

Reflective experiences occur several times throughout the academic year, not just at the end. The first reflection opportunity occurs within the first two weeks of the course. Since capstone project selection and assignment occurs at the end of junior year, the seniors arrive knowing their project assignment. After an introductory lesson, the teams begin a two-week mini-project to design, build and test an autonomous ground vehicle (AGV). They compete against their peers to navigate an indoor course. Points are deducted for failing to meet contest specifications, such as traversing a course boundary or hitting an obstacle. The three fastest teams to successfully complete the course receive a small bonus toward their grade for this project. Each team completes this small robotics project, regardless of the topic of their capstone project.

This is an exercise with multiple dimensions, technical and interpersonal. The teams have a stressful time constraint: only a few lessons in which to demonstrate a prototype. A working prototype requires both hardware and software components that must be appropriately integrated. Since the teams consist of students from different majors, most are working together for the first time. This initial exercise encourages the students to quickly bond as a team. Finally, this project is distinct from their capstone project for two reasons: First, it gives the team a smaller-scope project to experience a full design cycle before embarking on their capstone. Second, if this robotics project is unsuccessful, it allows the team to have a “fresh start” when they begin their capstone project.

At the end of the AGV project we ask the students to reflect on their experience both on the technical and interpersonal dimensions. On the technical dimension, the project report requires the students to explain how they tested the subsystems, how they performed integration testing, and to evaluate how their prototype met (or failed to meet) specifications. The AGV report evaluation rubric is shown in Appendix A. Regarding the human dimension, each student is required to submit a peer-assessment and self-evaluation in which they write at least one bulleted statement on each team member's strengths and areas needing improvement, as shown in Appendix B. All aspects of the project should be considered including technical work, planning, administration, writing, leadership, attitude, and initiative.

Three years ago, only teams containing electrical or mechanical engineers participated in this competition. Teams with exclusively computing majors (computer scientists and/or information technologists) were exempt. But the following year, after seeing the benefits, the directors of the computer science and information technology programs requested that all teams participate.

Sprint Reviews

Three years ago we developed an "agile-waterfall" design process to better accommodate projects with both hardware and software components (which had become the majority of our projects). We interleave the traditional "waterfall" process common to engineering disciplines with the agile methodology used in software development. Our process divides the remainder of the academic year (after the AGV mini-project) into five "sprints," two in the fall term and three in the spring. Each sprint is approximately four weeks long. A sprint begins with a planning exercise and ends with a sprint review and submission of the same peer evaluation form used for the AGV project (shown in Appendix B).

During the sprint planning exercise, the team decides upon a sprint goal, which is approved by their external sponsor or faculty advisor. The sprint review is a 10-minute video that lists the team's sprint goal and demonstrates to what extent that goal was achieved. Each person on the team is expected to explain the work they have done in support of the goal. If the goal was not achieved, or not fully achieved, the team must explain how the failure to fully achieve the goal will impact the overall project schedule and how they intend to keep the project on schedule. The sprint review evaluation rubric is shown in Appendix C.

The audience for the sprint review is the entire team, their instructor, any faculty involved as technical advisors, their customer (if available), at least one other capstone design team (each team is required to attend one other sprint review of their own choosing), one of the course directors, and another senior faculty member from the EECS department but in a different discipline than the course director. For instance, the electrical engineering course director would be accompanied by a senior faculty member in the computer science or information technology programs. If the customer is not able to attend the sprint review, they are requested to provide feedback by watching the video afterward. The sprint review video is posted to a customer-accessible site. This robust review panel gives the team substantive written and oral feedback on the execution of the design process.

The sprint review requires the team to intentionally reflect on their individual and collective performance. In addition to the video, teams submit the same peer-assessment and self-evaluation required in the AGV mini-project. A sprint is a short enough time that they can identify and correct problems without seriously jeopardizing the overall project. Before instituting sprints, teams would work on their design without serious reflection until the major design review. Since there were only three design reviews during the entire academic year, it was possible for serious flaws to go unnoticed until it was too late to completely remedy them.

As training for preparing their own sprint review, students are required to evaluate three sprint review videos from a prior year. The instructor selects exemplars of excellent, good and poor work. This year's students evaluate those videos using the rubric at Appendix C. Evaluating excellent sprint reviews using the grading rubric helps the students understand what constitutes excellent student work. Viewing poor student work forewarns the students of common pitfalls. The students are then asked to think about how they will organize their own teams to produce excellent work.

Design Reviews and Projects Day

On three occasions during the academic year, once in the fall and twice in the spring semesters, the capstone teams present design reviews. Whereas the sprint reviews focused on achievement of short-term sprint goals and the execution of the design process, the design reviews focus on how the prototype is meeting the overall design specifications. The design reviews are 30-minute presentations given by the entire team, with 15 additional minutes for questions. Large multi-department teams are allowed 40 minutes for the presentation and 20 for questions. The audience is the same faculty panel as for the sprint review except that other students are not required to attend. The evaluation rubrics for the Preliminary Design Review (fall) and Critical Design Review (spring) are included at Appendices D and E, respectively.

Design reviews require the students to present the project's goal and all specifications and constraints. The students present candidate designs that meet their requirements, explain their thought processes, and justify their design choices. They also present a plan to accomplish all remaining tasks in time to have a working prototype at "Projects Day," an institution-wide event where seniors from all academic majors present capstone projects, senior theses, or other scholarly work relevant to their discipline.

For Projects Day, the EECS Department holds a three-hour symposium in a trade-show format where all projects are on display in a large ballroom. A team of external judges evaluates projects for departmental awards. There are usually hundreds of visitors ranging from local high school students to senior executives representing the sponsoring agencies. Each team has a poster, a short video summarizing their project, and a table with their prototype on display. Each team prepares an "elevator speech" succinctly describing their project's goals and accomplishments. Every student is able to give the "elevator speech" as well as describe in detail their own contribution to the project. The process of preparing these artifacts are in themselves reflection activities.

Reflection Seminars

After each design review, all the students in the capstone course meet in an auditorium for a "reflection seminar." They spend the entire two-hour lesson period reviewing their experience in the course so far, with a focus on the most recent sprint and design reviews. The students are required to bring their evaluation of another team's sprint review that they attended. Due to time constraints, teams are required to watch another team's sprint review but not attend another team's design review. This lesson is led by a facilitator, one of the authors of this paper. The format of the lesson is based on her personal experience with contemplative dialog [10] and communal discernment [11] in non-engineering contexts.

The lesson begins with an orientation, since this is a completely foreign experience for most engineering students. First, the facilitator explains the purpose of this reflection seminar: for students to think about their thought processes (metacognition) in order to develop insights about their project, their team dynamics, and themselves. These insights may help them develop better and more creative ideas for their design and help their team function more cohesively. The students are introduced to the wisdom of Steve Jobs,

> "To design something really well you have to get it. You have to really grok what it's all about. It takes a passionate commitment to thoroughly understand something – chew it up, not just quickly swallow it. Most people don't take the time to do that. Creativity is just connecting things. When you ask a creative person how they did something, they may feel a little guilty because they didn't really do it, they just saw something. It seemed obvious to them after awhile. That's because they were able to connect experiences they've had and synthesize new things. And the reason they were able to do that was that they've had more experiences or have thought more about their experiences than other people have. Unfortunately, that's too rare a commodity [12]."

Since this seminar will involve an extended period of silent thought, which may feel uncomfortable, the students are reminded of Thomas Edison's assertion, "The best thinking has been done in solitude. The worst has been done in turmoil [13]."

Then the facilitator explains the format: Students will spend two minutes silently reflecting on a set of questions, followed by a 15-minute discussion within their capstone team. To reduce the noise in the auditorium, teams are encouraged to move to nearby spaces, such as an empty classroom or a foyer. (They are allotted 5 minutes for travel, so this portion takes 20 minutes.) This will be followed by 15-20 minutes of discussion within the whole course, where the facilitator invites teams to share their salient findings. The facilitator moderates the discussion and invites faculty to provide alternative perspectives, as appropriate. Finally, the facilitator summarizes the key points of the discussion. This process is repeated with two more sets of questions. The same question set is used for all reflection seminars.

Before providing the first set of questions, the facilitator explains a few "ground rules." First, any criticism must be constructive and presented in the way the speaker would want to receive it. Second, all participants must be open to change in their own attitudes, thoughts, and behaviors. Third, all participants must be willing to recognize their own responsibility for any shortcomings.

The first set of reflection questions concerns the student's contributions in the most recent sprint:

- What are our team dynamics?
- How did we decompose the large sprint goal into smaller tasks?

- How well did students within my own major communicate and cooperate? How well did I communicate and cooperate with students from other majors?
- What could I do differently in the next sprint to make the team more effective? What should I keep doing?
- Is our team on track for success at Projects Day?
- How will I incorporate feedback I have received into the next sprint?

The second set of reflection questions concerns the other team whose sprint review the student evaluated:

- What is their project's purpose?
- What was their sprint goal?
- Are they on schedule for success at Projects Day?
- What did you learn from their presentation?
- Which (if any) of their practices would be beneficial for your team to adopt?

The third set of reflection questions concerns the team's preparation for and response to the most recent design review:

- How long before your design review presentation did you send your slides to your instructor for feedback?
- How did you incorporate their feedback into your presentation?
- What feedback did you receive from the design review panel?
- How will you incorporate all the feedback into your design? Are there recommendations you will choose not to incorporate? Why?

Results

Analysis of changes to a system as complex as a capstone project course is not straightforward. Our results go beyond ABET assessment processes, which usually compare a course or event grade to a prior iteration and assume the effect of changes can be observed within a semester. When the desired outcome is phrased in terms of a specific skill, such as "an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics [14]", such a comparison is appropriate. However, we consider assessment of the effect of reflection and metacognition to be a more nuanced process. We are seeking changes in a student's interior state that may be only partially reflected by changes in behavior and may require a longer timeframe than an academic year. Additionally, we are seeking fundamental changes that will persist after graduation, much like the former ABET Criterion 3i, "an ability to engage in life-long learning [15]."

More consistent pace of work

Nonetheless, we have quantitative and qualitative measures that indicate changes due to reflection and metacognition have had a beneficial effect. Internally, we have observed that the pace of student work has improved. The department's machinist and electronics technician who assist in prototype fabrication used to offer extended hours of operation the day prior to Projects Day. That was necessary due to the number of teams who had significant fabrication needs at the last minute. Extended hours are no longer required. Support requests are more evenly spaced throughout the year and no technician overtime is incurred.

Greater team cohesion

Additionally, the multidisciplinary teams are more cohesive. Students no longer view their project as a collection of discipline-specific sub-components. Prior to our changes, students who were electrical engineers might use phrases such as "the electrical engineering requirements are . . . " Mechanical engineers or computer scientists on the same team would refer to their own set of requirements, without reference to the electrical engineers' list. At the first design review it was evident that the requirements were at best loosely coordinated among the disciplines. For example, the mechanical engineers might state a requirement for a tele-operated drone to have a range of 10 miles, but the electrical engineers have made no provision for a communications system with a 10-mile range. There was often an adversarial mentality among the disciplines, particularly in teams that spanned departments. Now students speak of project requirements and refer to themselves simply as members of "the DARPA Swarm Challenge" or the "Solar Decathlon" team.

Increased student engagement

Student engagement in their project has generally increased. The number of student-authored papers based on the capstone project work has fluctuated somewhat over the last five years, but showed a significant increase last year. The papers in Table 1 all have students as first author and have been published in a peer-reviewed conference or journal. The capstone course does not require students to submit work for publication nor do students receive any grade benefit for doing so. Their only reward is a sense of satisfaction and an item for their resume.

Favorable external feedback and increased sponsorship

Feedback from external sources has been extremely positive. The projects' customers, who range from other departments in our institution to government agencies such as the National Security Agency; the Tank Automotive Research, Development, and Engineering Command; the Program Executive Office for Ammunition; and the US Army Space and Missile Defense Command; value the teams' work and continue to fund projects from year to year. Since our sponsors have been extremely satisfied with the quality of student work, the number of externally-funded projects has increased 37% over the last five years, as shown in Table 1.

The reports from the panel of external judges who evaluate our capstone projects at the annual "Projects Day," are consistently favorable. Last year, a veteran judge who has decades of experience as a software engineer for Bell Labs and its successors remarked, "Each year we report that the overall quality is better than the previous year. We don't know how you can sustain this, but you do [16]."

External awards

Our capstone project teams occasionally compete in external competitions. Over the last three years, at least one EECS team per year has won external recognition. In 2017, one team won the Scott R. Clark Innovation for Soldiers award for the most innovative project across all the departments at our institution. In 2018, the West Point team won 2nd in design and 5th in auto-navigation at the 26th Annual Intelligent Ground Vehicle Competition (IGVC) in Michigan. This year, one of our largest and most diverse teams won the U.S. Department of Energy's 2019 Solar Decathlon competition in the Suburban Single-Family category. While not solely a result of reflection, we believe that reflection made a significant contribution. Each of these teams was a multi-disciplinary team where the improved pace of work and team cohesion were instrumental for their success.

Anticipated longer-term benefits

We anticipate that our varied reflection exercises throughout the capstone project experience may produce longer-term beneficial effects in our students. A visiting professor, Dr. Marilyn Nelson, taught West Point cadets mindfulness techniques as part of a one-semester poetry course nearly 20 years ago. She found that several of them, when deployed to Iraq or Afghanistan years later, continued to use the techniques she taught them. They found the practices helpful in managing the stress of combat [17]. Their experiences echo those of Major General Walter Piatt, commander of the coalition forces in Iraq. He asserted that mindfulness allowed him to "reduce conflict by better understanding [6]." We plan to conduct follow-up surveys to determine if there are longer-term effects in our students.

Table 1: Externally Supported Projects and Publication Count by Year

Year	Quantity of Externally-Funded Projects	Publication Count
AY15	8	5
AY16	8	8
AY17	9	3
AY18	9	7
AY19	11	TBD

Conclusions

We have introduced a series of deliberate reflection exercises, some conducted privately by students in silence, some held in lively group discussions, across the span of a two-semester capstone engineering course. We believe some of these experiences could be adopted in two-semester capstone courses found in many universities. These reflective techniques have consistently yielded a marked improvement in the pace and quality of student work throughout the three-year period of implementation. Students develop more insightful and creative designs, form better relationships with team members, and demonstrate deeper understanding of their product and how it satisfies customer requirements.

References

[1] Plato, "Apology," in *The Dialogues of Plato*, J.Kaplan, Ed. Pocket Library, 1950.

[2] S. L. Shapiro, K. E. Lyons, R. C. Miller, B. Butler, C. Vieten, and P. D. Zelazo, "Contemplation in the classroom: A new direction for improving childhood education," *Educational Psychology Review*, vol. 27, no. 1, pp. 1–30, 2015.

[3] B. Bernárdez, A. Durán, J. A. Parejo *et al.*, "A controlled experiment to evaluate the effects of mindfulness in software engineering," in *Proceedings of the 8th ACM/IEEE International Symposium on Empirical Software Engineering and Measurement*. ACM, 2014, p. 17.

[4] B. Rieken, M. Schar, S. Shapiro, S. Gilmartin, and S. Sheppard, "Exploring the relationship between mindfulness and innovation in engineering students." in *Proceedings of the American Society for Engineering Education Annual Conference, June 25-28. Columbus, OH.*, 2017.

[5] D. Goleman, "Here's what mindfulness is (and isn't) good for," *Harvard Business Review*, September 28, 2017.

[6] M. Richtel, "The latest in military strategy: Mindfulness," *The New York Times*, April 5, 2019, last accessed 27 April 2019. [Online]. Available: https://www.nytimes.com/2019/04/05/health/military-mindfulness-training.html

[7] S. D. Parks, *Big Questions Worthy Dreams: Mentoring Emerging Adults in Their Search for Meaning, Purpose and Faith*. Jossey-Bass, 2011.

[8] J. E. Salt and R. Rothery, *Design for Electrical and Computer Engineers*. John Wiley and Sons, 2002.

[9] K. S. Rubin, *Essential Scrum: A Practical Guide to the Most Popular Agile Process*. Pearson Education, 2013.

[10] L. Sweeney, "Moving into a deeper communion: Communal discernment through contemplative dialogue," *LCWR Occasional Papers*, vol. 43, no. 2, pp. 5–8, 2014.

[11] C. Shinnick, "The discipline of communal discernment," *LCWR Occasional Papers*, vol. 43, no. 2, pp. 9–11, 2014.

[12] G. Wolf, "Steve Jobs: The next insanely great thing," *Wired*, 1996, last accessed 1 February 2019. [Online]. Available: https://www.wired.com/1996/02/jobs-2/

[13] T. Edison, “Thomas a. edison quotes,” *AllAuthor*, 2019, last accessed 2 February 2019. [Online]. Available: https://allauthor.com/quotes/9484/

[14] Engineering Accreditation Commission, “Criteria for accrediting engineering programs, 2019-2020,” 2018, last accessed 31 January 2019. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/#GC3

[15] ——, “Criteria for accrediting engineering programs, 2014-2015,” 2013, last accessed 31 January 2019. [Online]. Available: http://www.abet.org/wp-content/uploads/2015/04/E001-14-15-EAC-Criteria.pdf

[16] J. Bentley, “Veteran judge for EECS projects day,” 3 May 2018, remarks at the departmental outbrief.

[17] M. Nelson, “The fruit of silence,” *Teachers College Record*, vol. 108, no. 9, pp. 1733–1741, 2006.

Appendix A: AGV Report Evaluation Rubric

XE401 AGV Project Report Grading Rubric

1. Design description (50) _________

    - ☐ Title Page, Table of Contents

    Problem Definition

    - ☐ Introduction
        - Describes the problem context in own words
    - ☐ Problem Statement/Product Vision
        - A short paragraph discussing the engineering problem to be solved

    Requirements Analysis

    - ☐ Backlog lists specified and implied requirements
    - ☐ Include constraints on equipment and time

    System Design

    - ☐ Functional Block Diagram
        - Reflects "as built" system, not "as designed" (updated from the IPR)
        - Includes signal characteristics and microcontroller ports used
    - ☐ Flow chart or algorithm for your software
        - Reflects "as built" system, not "as designed" (updated from the IPR)
    - ☐ Design Methodology
        - Describes a solution using some or all of the available sensors
        - Consistent with the Block Diagram and Flow Chart / Algorithm presented
        - Explain and justify any design changes from the IPR

    Detailed Design, System Integration & Test

    - ☐ Subsystem Design and Tests
        - Describes how each subsystem was designed / operates
        - Tests and results for each subsystem (i.e. how the function was confirmed)
    - ☐ Integration tests and results
        - Describes how (the process through which) the subsystems were integrated, a systematic process
        - Includes how the code was integrated
        - Tests and results for the system as a whole

    Properly Functioning System

    - ☐ Final Results
        - Includes the results from the Project Demo
        - Includes a photo of the completed design
        - Expands/explains the results (ie. more than a list of the results)
    - ☐ Conclusions

    Additional Information

    - ☐ References
    - ☐ Code submission: originality, effectiveness, adherence to algorithm, provide the URL to the GitHub repository.

2. Peer Eval Submitted (5) _________

3. Robot and Parts kits turned in, lab space cleaned (5) _________

4. Format, Writing Quality (15) _________

TOTAL (75) _________

Appendix B: Peer Evaluation Form

EECS Senior Design Project
Peer and Self Assessment

NAME ____________________Project: ___________________ Date: ____________

<u>Instructions:</u>
Step 1: Multiply the number of team members from all disciplines/majors by ten:

10 x _____ = _____

Step 2: Allocate the total number of points computed above among team members, including yourself, based on effort and contributions to the project during the rating period. All aspects of the project should be considered (technical work, planning, administration, writing, leadership, attitude, initiative, etc.)

Step 3: For each team member, write at least one bullet statement on that person's strengths (+) and areas needing improvement (-). Be specific and include yourself! **Include ALL members of the team, regardless of major. Add rows as necessary.**

ALLOCATE POINTS TO **ALL** TEAM MEMBERS, BEGIN WITH <u>YOURSELF</u>:

Team Member	Observations	Points
YOU	(+) (-)	
	(+) (-)	
	(+) (-)	
	(+) (-)	

Appendix C: Sprint Review Evaluation Rubric

Team: __________________ Evaluator: __________________ Sprint #: _______

Sprint Review Grading Rubric

Capacity: __________ (50) Capacity = Scope*Contributions

_____ Scope: Apparent/Expected hours (allowable range: 1.25 to 0)

______ = Apparent effort hours *(Evaluator may deduct hours from excessive claims)*

______ = Expected (hrs) = # *cadets* * (# lessons in Sprint * 2.75 hr)

Demonstration of expected Agile and engineering design process planning, execution, and communication.

Individual Contributions	All (25)	Most (20)	Some (15)	None (0)
Demonstrated Results				
Justified Changes From Plan				

_________ (50) Contributions

Goal Assessment: _____ (5)

Portion of the Sprint Goal fulfilled by delivered products which result from effort during this sprint.

Fully achieves Sprint Goal	Mostly achieves Sprint Goal	Falls well short of Sprint Goal	Not discussed
5(100%)	4 (80%)	3 (60%)	0

Reflection: _____ (10)

Recommendations for next sprint goal & Product Backlog items. Project Roadmap updated.

	Clear, insightful (5)	Adequate (4)	Marginal (3)	None (0)
Recommendations				
Roadmap				

Format and Style _____ (10)

- ☐ Presentation appearance: Correct grammar and spelling, consistent font and background legible text, included slide numbers
- ☐ Videos had appropriate image quality and volume
- ☐ Appropriate balance between video and "live" presentation
- ☐ Language: appeared rehearsed, appropriate use of technical terms. Did not use "filler" words such as "um, ah, you know."
- ☐ Demeanor: Used a pointer properly – did not point across body, did not hit the screen, or wave, swing, or play with pointer when not pointing to the screen. The team members not presenting did not fidget or otherwise detract from the presentation.
- ☐ Adhered to time limitation
- ☐ Had a person obviously record evaluator feedback and questions at end of briefing

Total ______ (75)

Appendix D: Preliminary Design Review Evaluation Rubric

Evaluator: ___________________________ Project: _____________________________

Preliminary Design Review Evaluation

50 pts	**1**	**2**	**3**	**4**	**5**
Clarify Design Objectives (Problem statement)	Did not attempt	Inadequate analysis	Moderately thorough	Thorough analysis	Exceptional insights, all assumptions stated and justified
Establish User Requirements (Requirements summary)	Did not attempt	Cursory attempt, but did not engage client	Moderately thorough	Thorough analysis	Exceptional insights, all assumptions stated and justified
Identify Constraints (Requirements summary)	Did not attempt	Inadequate-made unrealistic or unjustified assumptions	Moderately thorough	Thorough analysis	Exceptional insights, all assumptions stated and justified
Generate Design Alternatives	Only one design presented	Inadequate-one design is a "straw man" or "throw away" alternative	Moderately thorough. One alternative is more detailed, but both are viable.	Thorough development of both alternatives.	Generated more than 2 well thought-out alternatives.
Identify Subsystem Components	Only one component identified.	Inadequate-one component is a "straw man" or "throw away" alternative	Selected 2 or more viable components for each subsystem	Thorough analysis with well-chosen evaluation criteria.	Exceptional analysis with all criteria well chosen and components well researched.
Model or analyze design alternatives	Did not attempt	Cursory attempt at modeling or analysis.	Modeled or analyzed design with only minor errors.	Modeled or analyzed all sub-systems with only minor errors.	Modeled or analyzed all sub-systems with no errors.
Source Control	Did not attempt.	Repository appears to have been hastily constructed; contains few recent commits by a single team member.	Questionable use of Git by team consistently through lifetime of project, e.g., commit messages are unintelligible, use of multiple branches is non-evident.	Regular habit of version control is evident by team, but not yet following best practices (branch structure, commit messages, etc).	Mastery of Git version control system is evident. Strong history of commits clearly delineates provenance and alignment with Responsibility Matrix.

Likert Scale Average (1-5): ______ Conversion to points (1-50, using spreadsheet): ______

Comments:

Appendix E: Critical Design Review Evaluation Rubric

Evaluator: ___________________ Project: ___________________________

For ABET Assessment:
OUTCOME DEFINITION: an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
EVENT: Critical Design Review (Technical Audio Video and Oral Presentation)
FOCUS: "An ability to apply engineering design to produce solutions that meet specified needs" with a focus on technical requirements and economic constraints.

Critical Design Review Evaluation

	1	2	3	4	5
Clarify Design Objectives (Problem statement)	Did not attempt	Inadequate analysis	Moderately thorough	Thorough analysis	Exceptional insights, all assumptions stated and justified
Establish User Requirements	Did not attempt	Cursory attempt, but did not engage client	Moderately thorough	Thorough analysis	Exceptional insights, all assumptions stated and justified
Identify Constraints	Did not attempt- failed to consider time, money, power, safety, etc.	Made unrealistic or unjustified assumptions. Constraints not related to actual customer requirements.	System constraints identified and propagated to sub-systems. Industry-approved standards used.	Thorough analysis of how the system constraints propagate to sub-system design.	Clearly explains how each system constraint becomes a constraint or requirement for one or more sub-systems, using mathematically sound analysis.
Average for EE Program Student Outcome 2 (cells above) Enter into course spreadsheet for ABET assessment and point conversion					
Developed Test Plans	Did not attempt	Inadequate analysis	Moderately thorough	Thorough analysis	Exceptional insights, all assumptions stated and justified
Showed Hardware Test Results	Did not attempt	Cursory attempt, but failed to execute all tests.	Exectued tests for all available components.	Good analysis of all test data.	Conducted tests multiple times, good analysis of data.
Showed Software Test Results	Attempt at testing reflects poor coverage of source code's functionality. Nearly all test cases fail.	While some test cases are included, they would be very difficult to replicate by another programmer.	Replicable testing harness/procedure included, but insufficiently covering intended functionality.	Solid working test harness with test cases that sufficiently cover the source code's functionality. Some of the test cases may currently fail.	Excellent testing harness with numerous and sufficient tests. Code appears to be well tested, with all test cases passing.
Identified if components met requirements	Did not attempt	Determined for some components.	Determined for most components.	Determined for all components.	Determined for all components and had contingency plans for components that did not meet spec.
Average for Testing (cells above) Enter into course spreadsheet for point conversion					

Comments: