Capstone Design CONFERENCE 2022
JUNE 6–8, 2022 ▶ DALLAS, TEXAS

Incorporating Industry-based Metrics into a Specifications Grading System for Capstone Assessment

Joshua Gargac
Ohio Northern University

Capstone plays an important role in the curriculum, providing a means to assess the readiness of engineering students to enter the workforce. Traditional letter grades provide a reasonable assessment of student performance but are not typically used in industry to evaluate employees. This paper aims to bridge the gap between industry-based and traditional academic assessments by developing a new grading system. The new system incorporates performance evaluation metrics commonly used in industry into a specifications-based assessment scheme. Rubrics were developed to describe the expectations required to pass each specification. Student surveys were administered both before and after the new grading system was used. Overall, students responded positively to the industry-based grading system.

Keywords: Assessment, Industry, Specifications, Rubrics, Capstone

Corresponding Author: Joshua Gargac, j-gargac@onu.edu

Introduction

Teaching capstone is different since capstone courses are often serve to transition undergraduates from students to practicing engineers. Recent work has investigated how skills developed during capstone projects translate to work after graduation[1]. Capstone courses more closely resemble an engineer's work in industry than the typical academic course, but significant differences still remain between capstone and employment. The name capstone implies a final obstacle or test, where the students must synthesize their collegiate experiences to reach a threshold score on design, analysis, and professional skill assessments. Moreover, instructors often are required to use academic assessments to evaluate ABET student outcomes. In the end, capstone courses occupy a strange hybrid space: differing from the typical course but not quite an industrial experience.

How should students be assessed in this hybrid experience? Most universities require a letter grade assignment to measure student performance. These grades are a familiar tool to both faculty and students, but are solely constrained to the academic experience. After graduation, hired engineers are subject to a much different system for personal evaluation. Kremer and Burnette suggested incorporating industry-based performance reviews to evaluate professional skills development during capstone[2]. In this system, professional skills were evaluated as *unacceptable, meets expectations*, or *true professional*. This system was reported to encourage personal growth and engineering identity[2]. Starting in the 2016-17 academic year, a similar system was used to evaluate student work in the mechanical engineering capstone sequence at the author's institution. Students were told that *meeting expectations* would result in a "A" grade for the course. Anecdotally, industry-based metrics simplified grading while creating a framework to provide constructive feedback to students. However, some students found this determination of final letter grades to be too vague when compared with other courses.

A specification grading system has recently been suggested for capstone[3] and could potentially provide clarity when paired with industry-based assessments. Specifications grading is described by Nilson[4], and involves a checklist of criteria (or specifications) that must be met to receive specific grades in the course. Each assignment is graded pass/fail, with rubrics written with a "B" grade level as the threshold for passing. In such a system, a score of *meeting expectations* could be defined as equivalent to a "B" grade. A student's final grade would then be determined from the total number of specifications they pass.

Overall, the purpose of this paper was to 1) develop a new capstone grading system by combining the strengths of the industry-based evaluation metrics and a specifications grading system, 2) create rubrics defining the expectations for each specification, and 3) evaluate student perceptions regarding the grading system and overall capstone experience.

Student and Course Information

This study was conducted at the University of Mount Union, a private, liberal arts institution located in Alliance, OH. At the time of the study, nearly 2,200 students were enrolled at Mount Union, with approximately 170 majoring in one of the engineering disciplines. A total of 36 students were enrolled in the capstone sequence across the two years of this study (2019-20: 25 students; 2020-21: 11). At this institution, one faculty was assigned to lecture and advise all capstone teams (n=6 2019-21; n=3 2020-21).

Mechanical engineering students were required to take a year-long capstone sequence (6 credit hours total) during their final academic year (Tab. 1). Each week, students were required to meet for a lecture as a full cohort (105 min) and for progress meetings with their advisor as individual project teams (60 min). Specific project-related questions were addressed during the team progress meetings. The course lecture addressed a handful of topics related to engineering including professional practice, designing for sustainability, entrepreneurship, and engineering ethics. The capstone sequence was used to evaluate all seven ABET student outcomes.

Table 1: Capstone Schedule at a Glance

Week:	Fall	Spring
1	Problem Definition	Fabrication and Redesign (Ethics Module)
2		
3		
4		
5	*Requirements Review*	
6	Concepts	*Progress Update*
7		Fabrication, Redesign, and Performance Testing
8		
9	*Preliminary Design Review*	
10	Detailed Design	
11		*Prototype Demonstration*
12		Performance Testing
13	*Critical Design Review*	
14		
15	Ordering Materials	*Final Presentations*

Starting in the 2016-17 academic year, the course was re-organized and marketed to students as an industry-based experience. In this model, the instructor acted more like a manager setting deadlines to ensure the project remains on track and helping identify knowledge experts as needed. This approached differed significantly from a typical course where the instructor acts as an expert departing new knowledge to the students during lecture. Additional emphasis was made to treat students like employees when possible. Anecdotally, this organization helped reduce friction between the students and their faculty advisor, especially on projects from topic areas outside the expertise of the sole advisor.

Keeping with the industrial theme, all student work was evaluated as *exceeds expectations* (4 pts), *meets expectations* (3 pts), *below expectations* (2 pts), or *unacceptable* (1 pt.). The four-point scale was useful to quantify assessments for the evaluation of ABET performance indicators. Final grades were computed from assessments in the categories listed in Table 2. An ethics module represented significant portion of the lecture for the spring semester[5].

Table 2: Historic Capstone Evaluation (2016-2019)

Fall		Spring	
Reports and Presentations	50%	Reports and Presentations	20%
Personal Evaluation	25%	Prototype Score	20%
Peer Evaluation	25%	Peer Evaluations	20%
		Personal Evaluation	20%
		Ethics module	20%

A new grading system was introduced during the 2020-21 capstone sequence. The new grading system aimed to combine the benefits of the industry-performance evaluation metrics[2] with a specifications grading scheme[3-4]. For the fall capstone course, the following five categories were used to assess student work:

Individual Scores:

1. Acting as a member of a team
2. Acting as an engineer

Team Scores:

3. Communicating technical information
4. Completing design process activities
5. Designing an engineering solution

Each category contained 5 specifications (Tab. 3). Rubrics were developed to define the expectations required to pass each specification and have been attached in Appendix 1. The five CATME peer evaluation categories and rubric were used for the *Acting as a Member of a team* score[6-7]. Rubrics for the other categories were created using the CATME rubric as a guide. The language in the rubric borrowed heavily from the department's mechanical engineering ABET performance indicators and was influenced by the specifications described by Fernandez et al.[3]. Each specification was evaluated on a 5-point scale. To *meet expectations* for a specification, students needed to score a 3 on the rubric. Scores of 4-5, 2, and 1 were considered *exceeding expectations*, *below expectations*, *and unacceptable*, respectively.

For each category, meeting the expectations for all the associated specifications resulted in a "A" score. Each missed specification reduced the category score by one letter grade: 5=A, 4=B, 3=C, 2=D, ≤1= F. A student's overall course grade was calculated by first inserting the module grades into the Equation 1. The resulting score is similar to a calculation of *grade point average* (GPA). The associated letter grade is shown in Table 4. A "C" grade or higher was required for a student to progress to the spring semester capstone course. To prevent students from progressing without participating, the students were required to score at least a "C" in one of the individual score categories.

Table 3: Fall Semester Capstone Specifications

1. Acting as a member of a team [CATME[6-7]]
Contributing to team's work
Interacting with teammates
Keeping team on track
Expecting quality
Having related knowledge or skills
2. Acting as an Engineer
Contributing at progress meetings
Participating in lecture activities
Providing leadership
Displaying a positive attitude
Demonstrating the ability for self-directed learning
3. Communicating Technical Information
Demonstrating competency on the…
Preliminary report
Final design report
Requirements review presentation
Preliminary design review presentation
Critical design review presentation
4. Completing Design Process Activities
Planning and evaluating if project milestones are met
Developing realistic design requirements
Incorporating relevant standards and codes
Evaluating the sustainability of a design
Keeping a balanced budget
5. Designing an Engineering Solution
Developing, evaluating, and selecting design concepts
Prototyping design concepts
Applying failure modes and effects analysis (FMEA)
Using engineering calculations to predict performance
Creating plans enabling fabrication (CAD)

$$Score = [4(\#A's) + 3(\#B's) + 2(\#C's) + (\#D's)]/5 \quad \textbf{(1)}$$

Table 4: Overall Grade Assignments

Final Grade	Score	Final Grade	Score
A	3.8	C*	1.8
A-	3.6	C-	1.6
B+	3.4	D+	1.4
B	2.8	D	1.0
B-	2.6	D-	0.8
C+	2.4	F	<0.8

* C or higher was required to advance to 2nd semester

Assessment for the spring capstone course was also divided into five categories. The ethics module was graded using a traditional letter grade[5]. Two categories, *Acting as a member of a team* and *Acting as an engineer* used the same specifications as the Fall semester course (Tab. 3). Specifications for the remaining two categories are shown in Table 5.

Individual Scores:
1. Acting as a member of a team
2. Acting as an engineer
3. Ethics module

Team Scores:

4. Communicating technical information
5. Developing and conducting experiments

Table 5: Differing Spring Semester Specifications

3. Ethics Module
Graded Traditionally
4. Communicating Technical Information
Demonstrating competency on the ….
Engineering project poster
Final design report
Progress update presentation
Prototype demonstration presentation
Final advisory board presentation
5. Developing and Conducting Experiments
Planning and evaluating if project milestones are met
Developing experiments to test a hypothesis
Conducting experiments according to established procedures
Creating a quality, functioning product
Satisfying the original design requirements

Evaluation

Surveys were used to evaluate student perceptions of the grading system and overall capstone experience. The surveys were administered during the last course meeting of the spring semester. All questions were answered on Likert scale where *Strongly Disagree* was associated with a score of 1 and *Strongly Agree* was associated with a score of 5. The survey asked a series of questions about the industry-based grading scale (Fig. 1). Overwhelmingly, students responded positively, with most agreeing that they were fairly evaluated and were more willing to work hard on their project knowing that they would achieve a high letter grade. Additionally, most students preferred the industry-based evaluation metrics and suggested that the same metrics be used for future course offerings. Student evaluations also revealed a positive perception of the capstone assessments before and after the rubrics were introduced during the 2020-21 academic year.

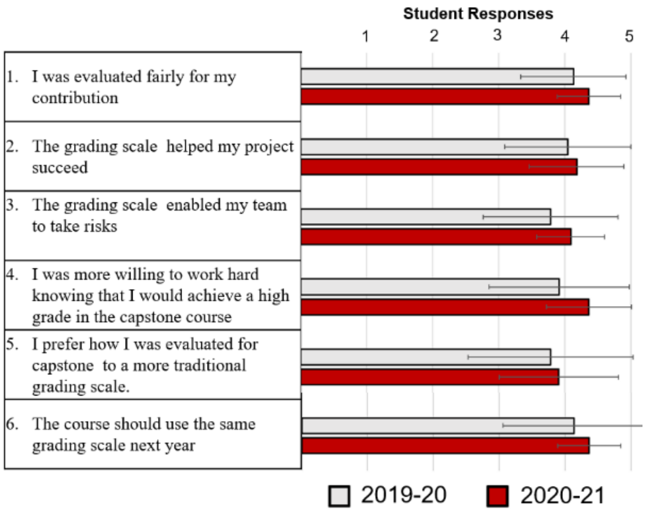

Figure 1: Student responses to questions regarding the grading scale.

The survey also asked a series of questions about the overall capstone experience (Fig. 2). Students overwhelming enjoyed the capstone course and working with their capstone advisor. From an advisor standpoint, the industry-based evaluation metrics enabled positive interactions with the students. By scoring performance as below expectations, instead of a *C* or *D*, the students seemed more receptive to feedback. Additionally, it was easier to sell a "growth mindset" to the students when the consequences of failure were less severe to their final grade.

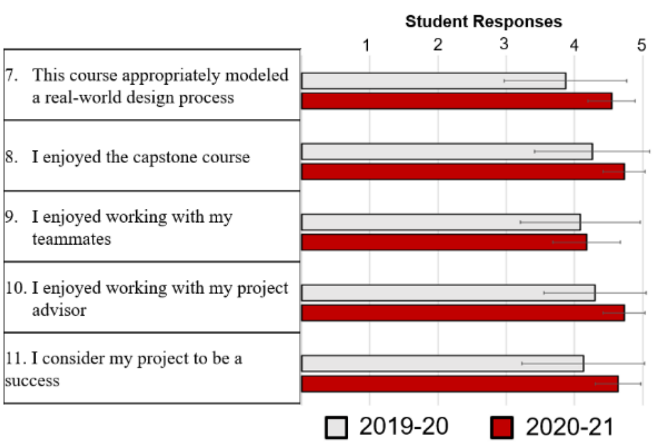

Figure 2: Student responses to overall capstone assessment questions.

Conclusion

A specifications-grading system incorporating industry-based performance evaluation metrics was developed and deployed in a year-long capstone sequence. Overall, the new rubrics (Appendix 1) simplified the process of capstone assessment while providing clear metrics to both faculty and students. Student survey responses revealed a preference for the grading scheme compared to traditional courses.

Data from this study was tracked during the COVID-19 pandemic. While most of the 2019-20 year was normal, the 2nd half of the spring semester was forced to remote instruction. Most the teams could not finish fabricating their projects. The 2020-21 year was entirely in-person under a social-distancing learning model. These extenuating circumstances may have affected the student responses.

This work was performed in a small mechanical engineering program with only nine capstone projects across the two years of analysis. The *Acting as an Engineer* rubric would likely need to be adjusted to better scale for programs enrolling more students.

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Appendix 1 – Rubrics

2. Acting as an Engineer Rating Scale

	Score	Contributing at progress meetings	Participating in lecture activities	Providing leadership	Displaying a positive attitude	Demonstrating the ability for self-directed learning
Exceeds	5	• Completes weekly work with exceptional quality • Always behaves professionally during meetings • Arrives early for meetings	• Is ready for the start of class • Fully engages in class discussion • Puts creative effort into class activities	• Uses progress meeting time effectively • Asks for or shows interest in teammates' ideas and contributions • Ensures that the team is making appropriate progress	• Displays enthusiasm for project or class activities • Communicates positively and encouragingly with project stakeholders • Willingly accepts challenging or less interesting tasks	• Submits a high-effort reflection • Explains multiple examples of acquiring new knowledge or skills • Clearly articulates their significant, unique project role
	4	Demonstrates behaviors described immediately above and below				
Meets	3	• Comes prepared with evidence of weekly work • Speaks or presents during meetings • Arrives on time to meetings	• Arrives to class on time • Contributes to class discussions • Participates in class activities	• Follows an agenda for progress meetings • Listens to teammates and respects their contributions • Knows what the team should be doing and notices problems	• Displays positive body language • Uses professional language when communicating with project stakeholders • Willingly seeks aid to work through challenging tasks	• Submits an essay of appropriate length • Explains one example of acquiring new knowledge or acquiring new knowledge or skills • Mentions at least one specific, unique role
	2	Demonstrates behaviors described immediately above and below				
Unacceptable/Below	1	• Brings little or no evidence of personal work • Remains silent during progress updates • Arrives late or misses meetings	• Arrives late or is absent • Does not contribute to class discussion • Does not participate in class activities	• Submits late or forgets to submit a meeting agenda • Interrupts, ignores, or prevents teammates from participating • Is unaware whether the team is meeting its goals	• Displays poor body language • Uses unprofessional language when communicating with project stakeholders • Avoids or is easily overwhelmed by challenging or less interesting tasks	• Submits a low effort or short essay • Does not submit an essay • Does not explain examples of acquiring new knowledge or acquiring new skills • Does not describe a specific project role

3. Communicating Technical Information Rating Scale

	Score	Demonstrating competency on the preliminary report	Demonstrating competency on the final design report	Demonstrating competency on the requirements review presentation	Demonstrating competency on the preliminary design review presentation	Demonstrating competency on the critical design review presentation
Exceeds	5	• Effectively labels graphics to aid the reader • Submits a cohesive document that reads evenly • Excels when describing technical content • Demonstrates excellent literature search with abundant relevant citations	• Effectively labels graphics to aid the reader • Submits a cohesive document that reads evenly • Excels when describing technical content • Demonstrates excellent literature search with abundant relevant citations	• Effectively labels graphics to aid the audience • Enthusiastically delivers technical information in an engaging manner • Excels when describing technical content • Excels when describing the project motivation	• Effectively labels graphics to aid the audience • Enthusiastically delivers technical information in an engaging manner • Excels when describing technical content • Excels when describing the project motivation	• Effectively labels graphics to aid the audience • Enthusiastically delivers technical information in an engaging manner • Excels when describing technical content • Excels when answering committee questions
	4	Demonstrates behaviors described immediately above and below				
Meets	3	• Submits a document organized with appropriate graphics to clarify technical concepts • Submits a concise document that conveys a logical and evidence-based engineering case • Includes required content • Sources are cited using the ASME format	• Submits a document organized with appropriate graphics and equations to clarify technical concepts • Submits a concise document that conveys a logical and evidence-based engineering case • Includes required content • Sources are cited using the ASME format	• Uses appropriate organization • Creates visual aids incorporating appropriate graphics to clarify technical concepts • Presents technical information in an efficient and clear manner • Includes required content • Uses citations as needed	• Uses appropriate organization • Creates visual aids incorporating appropriate graphics to clarify technical concepts • Presents technical information in an efficient and clear manner • Includes required content • Uses citations as needed	• Uses appropriate organization • Creates visual aids incorporating appropriate graphics to clarify technical concepts • Presents technical information in an efficient and clear manner • Includes required content • Uses citations as needed
Unacceptable/Below	2	Demonstrates behaviors described immediately above and below				
	1	• Submits a document with organizational issues • Submits a document with errors • Poorly describes or does not include content • Is missing citations or does not follow ASME format • Submits the document late	• Submits a document with organizational issues • Submits a document with errors • Poorly describes or does not include content • Is missing citations or does not follow ASME format • Submits the document late	• Uses poor organization • Does not follow proper slide design guidelines • Poorly describes or does not include content • Is missing citations • Submits .pptx file late	• Uses poor organization • Does not follow proper slide design guidelines • Poorly describes or does not include content • Is missing citations • Submits .pptx file late	• Uses poor organization • Does not follow proper slide design guidelines • Poorly describes or does not include content • Is missing citations • Delivers design review package late

4. Completing Design Process Activities Rating Scale

	Score	Planning and evaluating if project milestones are met	Developing realistic design requirements	Incorporating relevant standards and codes	Evaluating the sustainability of a design	Keeping a balanced budget
Exceeds	5	• Creates a Gantt chart with specific dates for milestones • Meets milestones ahead of schedule • Regularly refers to Gantt chart to determine tasks	Develops design requirements that are: • Well-reasoned • Based on research, experimentation, or prototyping • Based on consumer or user feedback	• Completes a substantial summary of relevant codes and standards • Describes multiple relevant codes and standards used during the design process • Excels when explaining the importance of codes and standards for engineers	Designs a solution that is measured as: • Economically sustainable • Environmentally sustainable • Socially sustainable	• Completes purchase order forms before the design review • Keeps detailed part information in the OneDrive folder • Regularly updates budget document
	4	Demonstrates behaviors described immediately above and below				
Meets	3	• Gantt chart contains milestones for both semesters • Meets milestones as scheduled • Updates Gantt chart as needed	Identifies concrete and measurable requirements with consideration of: • Desired performance • Public health, safety, and welfare • Global, cultural, social, environmental, and economic factors	• Investigates relevant codes and standards • Describes at least one code or standard used during the design process • Explains the importance of codes and standards for engineers	Uses the sustainability rubric to evaluate a design's: • Economic sustainability • Environmental sustainability • Social sustainability	• Submits purchase order before winter break • Lists all parts, costs, and vendors in a table. • Anticipates future purchases and keeps expenses under-budget • Estimates and verifies shipping and tax charges
Unacceptable/Below	2	Demonstrates behaviors described immediately above and below				
	1	• Gantt chart is incomplete • Meets milestones behind schedule • Gantt chart is ignored after initial creation	• Develops requirements that are not concrete and measurable • Does not identify requirements in one or more relevant categories.	• Provides no evidence that codes and standards were investigated • Does not use codes or standards during the design process • Cannot explain the importance of codes and standards for engineers	• Does not submit or submits an incomplete sustainability analysis • Uses dishonest or incorrect information when evaluating sustainability	• Does not submit all purchase orders before winter break • Keeps poor financial records • Makes mistakes or ignores shipping or tax charges resulting in over-budget expenses

5. Designing an Engineering Solution Rating Scale

	Score	Developing, evaluating, and selecting design concepts	Prototyping design concepts	Applying failure modes and effects analysis (FMEA)	Using engineering calculations to predict performance	Creating plans enabling fabrication (CAD)
Exceeds	5	• Develops detailed CAD models for at least three feasible concepts • Bases decision matrix rankings on research, experimentation, prototyping, or user/consumer feedback	• Creates a high-quality prototype • Fully demonstrates product performance with the prototype • Iterates on a design with multiple prototypes	• Uses FMEA to develop an analysis plan • Submits a comprehensive FMEA	• Applies multivariate calculus and/or differential eqns to solve the problem • Validates assumptions • Completes convergence, sensitivity, and validation studies for finite element models	• Exactly models complex geometries • Consults with manufacturers to improve drawings • Uses GD&T to indicate proper tolerancing
	4	Demonstrates behaviors described immediately above and below				
Meets	3	• Develops at least three technically feasible alternative concepts • Compares concepts using a decision matrix • Selects a concept or generates a new concept influenced by matrix results	• Puts forth effort to create a prototype • Creates a prototype representing the design to scale • Uses the prototype to learn about the design or influence design decisions	• Breaks a complex system into component parts • Evaluates potential failure modes and their effects • Ranks the likelihood of each failure	• Applies the principles of math and science to solve an engineering problem. • Identifies assumptions used to constrain calculations • Creates diagrams to describe calculations • Applies modern engineering tools and software (FEA, MATLAB, etc)	• Enables the visualization of the design with 3D modeling • Creates 2D drawings containing all necessary dimensions • Follows dimensioning standards • Shows exploded view and bill of materials on Assembly drawing
	2	Demonstrates behaviors described immediately above and below				
Unacceptable/Below	1	• Develops less than three technically feasible concepts • Does not complete decision matrix • Shows little understanding of matrix results	• Puts forth little effort to create a prototype • Creates a prototype that does not represent the design or is not to scale • Prototype does not demonstrate product performance	• Treats the design as a system instead of component parts • Ignores obvious failure modes • FMEA is incomplete	• Avoids difficult analyses • Is missing needed calcs • Relies entirely on FEA • Ignores assumptions • Poorly describes calculations • Poorly describes FE models • Does not apply modern engineering tools and software	• CAD models do not represent the design • Does not create 2D drawings for each fabricated part • Is missing dimensions or does not follow standard • Is missing assembly drawing