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Specifications Grading in an Undergraduate Engineering Dynamics Course

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Abstract

Dynamics is a core undergraduate mechanical engineering course that often acts as a gateway to upper division engineering curriculum. Some students find the course exciting and motivating while others find it overly challenging and discouraging. Grading schemes can play a significant role in students' motivation for, and approach to, learning. In this article, we present two different grading schemes used in an undergraduate engineering dynamics course at the University of California, Irvine, and specifically evaluate the merits of a standards-based, learner-centered, specifications grading scheme for promoting student learning and overall achievement. The first grading scheme we present is a traditional points-based scheme that assigns points to students' performance on summative assessments like quizzes and exams. The second grading scheme uses specifications grading, without points, to assess all assignments as either demonstrating sufficient mastery of the course learning objectives or otherwise needing revision. This specifications grading scheme allows for assignment revisions and resubmissions and clearly defines assessment criteria and standards for passing assignments and earning a particular grade. This shifts students' focus from accumulating points to mastering the learning objectives and promotes metacognition of learning and improving.

We describe the course learning objectives and the two different grading schemes, along with details of how the assessments in specifications grading were designed. Then we present students' performance in both grading schemes and students perceptions on how specifications grading affected their learning, anxiety, and self efficacy, as collected in midterm and end of term surveys. In general, students reported feeling that the specifications grading scheme helped them learn and gave them confidence to earn their desired grade, although some students reported that the specifications grading scheme was more stressful than traditional points-based grading. Finally, we discuss the advantages and challenges, from the instructor's observations and perspective, associated with transitioning from a traditional points-based grading scheme to using specifications grading.

Introduction

Different instructors have different perspectives on the purpose and utility of grades. One common understanding is that grades should reflect students' achievement or mastery of course learning objectives. Traditional points-based approaches to grading are common in college-level courses, but these approaches unfortunately emphasize the extrinsic motivational factor of accumulating points rather than the intrinsic motivation of mastering the course learning objectives [1, 2]. Furthermore, the variation in scores given in points-based grading by different instructors and teaching assistants may require curving or adjusting grades in a way that is not consistent between courses or sections. This may lead to uncertainty in grades and student anxiety. Students may also be disincentivized to collaborate with one another if their grades are dependent on their peers' grades. These drawbacks to traditional points-based grading may result in a cumulative score, and resulting grade, that may not reflect what students have learned, and may not effectively incentivize students to learn or employ best practices in learning.

There are variations to points-based grading that affect how students learn, their motivation, and outcomes. For example, grading using different incentives, such as students earning points versus students losing points, has been shown to motivate students differently [3]. Goal structures in a grading scheme, such as cooperative, competitive, or individualistic, place implicit value on certain behaviors, thereby acting as an "unconscious curriculum" that affects student learning and outcomes [4]. Traditional grading schemes, such as a points-based scheme and grading on a curve, act as a competitive goal structure in which students are expected to outperform their peers. This structure generally does not promote grades as a metric for individual mastery or competence in the course's learning objectives. Course grading and goal structures often promote mastery-oriented learning, in which students seek to improve their competence and seek challenges, or performance-oriented learning, in which students seek favorable scores of their competence [5]. Both goal orientations are important but have advantages and disadvantages. Goal structures have been studied in engineering courses. For example, researchers at the University of Colorado Boulder implemented and studied an alternative exam format in an aerospace engineering course, consisting of quizzes and an optional final exam rather than two high-stakes midterm exams and comprehensive final exam, to help inform the development of achievement goal structures in large engineering classes. Students in the course perceived the alternative format to be more mastery-oriented and the traditional format as more performance-oriented [6].

In contrast to points-based grading, standards-based grading and specifications grading emphasize the mastery of course learning objectives and the metacognitive process of students' revisiting their work to understand where they could improve and revising and resubmitting their work to improve their grades. These grading schemes also emphasize clear standards or criteria for earning grades that are independent of how other students perform in the course; students' work is graded based on meeting criteria or not. For example, assignment grades could be binary (pass/fail) or have multiple levels, such as "High Pass", "Low Pass", or "Needs Revision". The final course grade is then determined by the number of learning objectives mastered. These schemes focus on formative assessment, providing students and instructors feedback on the learning process and how to improve [7]. Commonalities and differences between criteria-based grading and standards-based grading and discussion of interpretations of criteria-based assessment and grading in higher education are presented in [8]. Specifications grading builds on principles from mastery-based grading [9], standards-based grading [10], and contract grading, and importantly includes a mechanism for students to revise and resubmit their work so that they can improve their learning and maintain their motivation. It was popularized in 2014 by the book by Linda Nilson [11], and a readiness assessment tool has been developed for instructors considering transitioning to specifications grading [12]. In this way, specifications grading can maintain course rigor, motivate students to learn, align grades with demonstration of learning objectives, and improve “fairness” of grades, all while reducing grading time.

Specifications grading has been implemented and evaluated in several different contexts. Examples include using specifications grading in two math courses [13], in an organic chemistry laboratory course [14], in a chemistry writing course [15], in laboratory courses with over 1,000 students [16], and in a biology course [17]. A study involving the integration of a standards-based grading system in five science, technology, engineering and mathematics (STEM) courses found that standards-based grading improved students’ self-efficacy and was perceived as valuable by the students [18].

In engineering, there are examples of using both standards-based grading and specifications grading. They are closely related with a focus on students demonstrating mastery of standards or criteria based on learning objectives rather than accumulating points to earn a grade. Standards-based grading has been implemented in engineering courses, such as mechanics of materials [19], fluid mechanics [20], thermodynamics [21], and project-based design courses [22]. Specifications grading has also been implemented in various engineering courses. For example, three case studies of implementing specifications grading to demonstrate how it can be used in different types and levels of engineering courses are presented in [23]. Other descriptions of specifications grading in engineering include courses on thermodynamics [24, 25], bioelectricity [26], general and engineering physics [27], fluid mechanics [28], system modeling [29], and capstone design [30].

Benefits, best practices, and obstacles of designing and implementing standards-based and specifications grading in engineering courses have been outlined in the literature [31, 19, 21]. The benefits include clear and consistent grading and feedback for students, connection of assessments to specific learning objectives, reduction of time spent grading, improved student learning, and effectiveness for program assessment. Best practices include establishing a manageable set of learning objectives at the beginning of the course that can be assessed multiple times throughout the course, with rubrics that clearly explain expectations for how the objectives will be assessed and how the final course grade will be assigned. Identified obstacles include a lack of familiarly with the new grading scheme from both students and instructors, increased initial workload for instructors to transition to a different grading scheme, and practical considerations such as how to implement the grading scheme in existing course management systems [31].

In this work, we present a specifications grading scheme for an engineering dynamics course. We describe the course structure and assessment and grading criteria in the following sections. Then we present and compare students’ performance in two offerings of the course that employed specifications grading with two offerings of the course that employed traditional points-based grading. Finally, we present students’ perspectives on the specifications grading scheme, with specific interest on whether or not students perceived the specifications grading scheme to be helpful for learning, stressful or not compared to traditional grading, and to give students confidence to earn a desired grade in the course and to succeed in future courses.

Course Overview

In this work, we compare four offerings of an engineering dynamics course offered by the same instructor in the spring of 2020, 2021, 2022, and 2023. The class follows Chapters 11 through 17 of the textbook *Vector Mechanics for Engineers: Dynamics* by Beer, Johnston, Cornwell, and Self [32], and is divided into three main parts, or modules:

- Module 1: Chapters 11-13, Kinematics of Particles
- Module 2: Chapters 14-15, Systems of Particles and Kinematics of Rigid Bodies
- Module 3: Chapters 16-17, Planar Motion of Rigid Bodies

The course meets for two 80-minute classes and one 50-minute discussion section per week, and because the university's academic calendar is split into quarters, there are a total of 10 weeks of instruction in the term. In discussion sections, students get additional practice working on problems related to their homework with their peers and instructors. All course content and assignments are organized using the Canvas learning management system [33]. The 13 course learning objectives are listed in the Appendix.

The course is required for mechanical and aerospace engineering majors, and it fulfills an elective requirement for civil and environmental engineering and materials science and engineering majors. Around half of students enrolled in the course are mechanical engineering majors, and one quarter are aerospace engineering majors. The remaining enrolled students are civil engineering or other majors. The majority of enrolled students have junior standing.

Table 1: Number of students enrolled and survey respondents

	Major				Survey respondents	
Term	Mech.	Aero.	Civil	Other	Midterm	End of term
Spring 2020 (n = 104)	47 (45.2%)	28 (26.9%)	7 (6.7%)	22 (21.2%)	N/A	N/A
Spring 2021 (n = 108)	60 (55.6%)	28 (25.9%)	8 (7.4%)	13 (12.0%)	N/A	N/A
Spring 2022 (n = 59)	29 (49.2%)	14 (23.7%)	8 (13.6%)	10 (16.9%)	N/A	N/A
Spring 2023 (n = 97)	59 (60.8%)	26 (26.8%)	11 (11.3%)	9 (9.3%)	80 (82.5%)	51 (52.6%)

The number of enrolled students and their majors are given in Table 1, along with the number of students who participated in the midterm and end of term surveys on specifications grading. Some students are double-majors, such as both mechanical and aerospace engineering students, so the sum of the students in different majors shown in Table 1 may be more than the total number of students. Majors in the "Other" category include: Environmental Engineering, Chemical Engineering, Electrical Engineering, Undeclared Engineering, Physics, Applied Physics, Economics, Math, Computer Science, Art History, Biological Sciences, Science Education, and Business Economics.

Points-Based Grading Scheme

In 2020 and 2021, course grades were determined using a points-based grading scheme. Each assignment was scored out of a certain number of points, and the course grade was calculated based on the given points and the weight of each group of assignments, as shown in Table 2. Letter grades were then calculated using the following cumulative percentages: A+ $\geq$ 96.5%, A $\geq$ 93.5%, A- $\geq$ 90%, B+ $\geq$ 86.5%, B $\geq$ 83.5%, B- $\geq$ 80%, C+ $\geq$ 76.5%, C $\geq$ 73.5%, C- $\geq$ 70%, D+ $\geq$ 66.5%, D $\geq$ 63.5%, D- $\geq$ 60%, F $<$ 60%.

Assignments included weekly homework, homework quizzes, and concept quizzes, attendance in weekly discussion sessions, submission of study sheets that were allowed to be used during the exams, three exams throughout the course, and participation in course surveys and evaluations earned extra credit. The quizzes were designed to provide more frequent formative assessments and reduce the weight of high stakes summative exams.

Table 2: Points-based grading scheme

Assignment Group	Weight
Homework	8%
Homework Quizzes	5%
Concept Quizzes	20%
Discussion Attendance	4%
Exam Study Sheets	3%
Midterm Exam 1	20%
Midterm Exam 2	20%
Final Exam	20%
Course surveys and evaluations (extra credit)	3%

Specifications Grading Scheme

Course grades were determined using a specifications grading scheme in 2022 and 2023. The course content and assignments remained similar but with slight redesign as needed so that each question on an assignment assessed one or more of the learning objectives (listed in the Appendix). Then student grades were determined by how many assignments they passed in multiple *assignment bundles*. Thus, grades were directly related to students' demonstration of the learning objectives.

Students could determine their course grade in the specifications grading scheme by using the "Grade Tracker" shown in Figure 1. The assignments were grouped into *bundles* based on the type of assignment: Homeworks (HWs), Homework Quizzes (HQs), Concept Quizzes (CQs), and Mini Exam Questions (MEQs). Besides HQs, each of these assignments was graded as "High Pass", "Low Pass", or "Needs Revision". HQs were graded as "Pass" or "Needs Revision". Then letter grades were assigned as the highest grade for which students met all of the criteria listed below each letter grade in the Grade Tracker.

For example, to earn a "B" in the course, a student must:

- pass at least 7 of the 8 HWs, meaning earning a "High Pass" or "Low Pass", with at least 5 of those being "High Pass"
- pass at least 4 of the 5 HQs
- pass at least 7 of the 8 CQs, meaning earning a "High Pass" or "Low Pass", with at least 5 of those being "High Pass"

- pass at least 5 of the 6 MEQs, with at least 4 of those being a "High Pass"

If any of these criteria are not met, students receive a lower grade for which all of the criteria are met. For example, if a student only passed 6 CQs but met the criteria for a B in all of the other assignment bundles, that student would receive a C.

A plus (+) or minus (-) was added to the letter grade based on how many MEQ retakes were used. Retakes are described below, along with the Token System.

Your grade is the highest category for which you meet all criteria.
See Canvas for each assignment's completion criteria/rubrics.

Assignment Bundles	✔ 8 Homeworks (HWs)		
	✔ 5 Homework Quizzes (HQs)		
	✔ 8 Concept Quizzes (CQs)		
	✔ 6 Mini Exam Questions (MEQs)		
Letter Grade			
A	**B**	**C**	**D**
☐ Pass 8 HWs (6 high pass)	☐ Pass 7 HWs (5 high pass)	☐ Pass 6 HWs (4 high pass)	☐ Pass 5 HWs (2 high pass)
☐ Pass 5 HQs	☐ Pass 4 HQs	☐ Pass 3 HQs	☐ Pass 2 HQs
☐ Pass 8 CQs (6 high pass)	☐ Pass 7 CQs (5 high pass)	☐ Pass 6 CQs (4 high pass)	☐ Pass 5 CQs (2 high pass)
☐ Pass 6 MEQs (5 high pass)	☐ Pass 5 MEQs (4 high pass)	☐ Pass 4 MEQs (3 high pass)	☐ Pass 3 MEQs (2 high pass)
Add a (+) to Letter Grade		**Add a (-) to Letter Grade**	
☐ No more than 1 MEQ retake		☐ 3 MEQ retakes	

Token System

Redeem tokens for:	**Cost (# of tokens):**	**# of opportunities:**
48-hour HW extension	1	3
CQ retake	1	3
MEQ retake	1	3 (1 MEQ per exam)
Everyone starts with 2 tokens. Earn more by:		**# of tokens earned:**
Completing how I earned an "A" assignment		3
Completing mid-quarter course evaluation		1
Completing course surveys		1
Attending 4 discussion sections		1

Figure 1: Grade Tracker for Specifications Grading scheme. Students could use this as a checklist to keep track of their course grade.

Assignment Bundles

Homework Problem Sets (HWs): Eight weekly HWs are assigned and submitted on the course learning management system. Problems are assigned from the textbook. A token can be used to receive a 48-hour extension on the HW due date; this can be done up to three times. Each HW is graded using the rubric shown in Table 3.

Homework Quizzes: Students work on weekly HQs in groups during class time. These quizzes cover material from the previous week's homework problems to assess comprehension of the problem solutions. They are online quizzes through the course learning management system with multiple choice or true/false questions. Students receive two attempts on all HQs, and the highest of the two scores is applied. All questions must be answered correctly to "Pass" the assignment. Tokens cannot be used.

Concept Quizzes: Students complete eight weekly CQs individually as online quizzes through the course learning management system outside of class. These are timed quizzes with five multiple choice or true/false questions related to the learning objectives for that week. Questions often show a figure and ask a conceptual question about the motion of objects in the figure. A token can

Table 3: Homework Grading Rubric

High Pass	Low Pass	Needs Revision
Homework is complete. Each problem is attempted with significant work setting up and solving the problem (e.g., defining known and unknown variables, drawing free-body diagrams, choosing an appropriate method and writing the equations, using physical information, etc., and solving the resulting equations for unknown variables).	Homework is almost complete. The majority of problems are attempted with work shown that sets up and solves the majority of problems.	Homework is not complete. The majority of problems are not attempted, or work is not shown to set up and solve the majority of problems.

be used to retake a CQ. The retakes are also timed online quizzes completed outside of class. Retakes are only allowed within one week of the quiz due date. A total of three CQ retakes are allowed. Each CQ is graded using the rubric shown in Table 4.

Table 4: Concept Quiz Grading Rubric

High Pass	Low Pass	Needs Revision
Answer 4 out of 5 questions correctly.	Answer 3 out of 5 questions correctly.	Answer fewer than 3 out of 5 questions correctly.

Example CQ questions:

1. *Consider a rotating (but not translating) rigid body. True or False: Multiple points on the rigid body can have the same velocity (note: we are not talking about speed).* This question assesses learning objective 1c.
2. *Consider kicking a soccer ball or rolling a bowling ball. If there is forward velocity and backspin (i.e., velocity to the right and counter-clockwise rotation), choose the two correct statements. a) There will be slipping. b) There may or may not be slipping. c) Friction acts to the left. d) Friction acts to the right.* This question assesses learning objective 5.

Mini Exam Questions: Students take three "mini exams" throughout the course. Each mini exam is taken in class after completing one of the three course modules. Each mini exam includes two free response questions (MEQs). One double-sided 8.5in×11in page of notes may be used during the mini exams. No other material is allowed. A token can be used to retake an MEQ (1 of the 2 MEQs per mini exam). The retakes are timed online quizzes (with free response questions for which students upload work) and are completed outside of class. Retakes are only allowed within two weeks after the mini exam date. The retake questions are different from the original question but assess the same learning objectives as the original question. Each MEQ is graded using the rubric shown in Table 5. All criteria must meet a given threshold ("High Pass", "Low Pass", or "Needs Revision") to receive that grade.

Table 5: Mini Exam Question Grading Rubric

Criteria	High Pass	Low Pass	Needs Revision
Choose an appropriate solution method	An appropriate method is chosen.	An appropriate method is chosen.	Does not apply an appropriate method.
Apply chosen method correctly	Applies method correctly.	Applies method with only minor mistakes.	An appropriate method is not applied or is applied incorrectly.
Solve the problem	Solution is almost completely correct and has no conceptual errors.	Solution is mostly correct, and any minor errors do not affect the overall method used to solve the problem and do not reflect conceptual errors.	There are significant errors. These may be conceptual errors, solutions with incorrect units, or significant mathematical errors.
Show all work	Work is clear and easy to follow. Notation is correct. Explanations are provided when necessary.	Work is clear and easy to follow. Notation is mostly correct. Explanations are included, but may not be complete.	Work is not clear or not shown.

Token System

We implemented a token system for students to retake and resubmit assignments and exams to improve their existing grades. Students begin with two tokens and have opportunities to earn more throughout the term by completing things like course surveys and evaluations or attending discussion sections; these things are useful for the students and the instructional team but are not things that assess specific course learning outcomes. Therefore, attendance and participation are rewarded with tokens rather than directly impacting students' grades (as they did in the points-based grading scheme). For example, students can complete an assignment called "How I earned an A in this class", which is similar to a syllabus quiz, to earn tokens at the beginning of the term. This is further described in the Discussion section below.

Students can use tokens to revise and resubmit certain assignments. A limited number of these are available, and they have to be completed by a certain time. This avoided potential issues, such as a significant amount of grading, that could be caused by many students resubmitting several assignments all at the end of the term. This also incentivized students to not wait to revisit their work and to stay on pace with the course material that builds on itself throughout the term.

Student Performance

Grade Distributions and Learning Objectives

The grade distributions from the four course offerings were compared using pairwise t-tests, and no significant differences were found. The smallest p-value was 0.325 when comparing grades from 2020, which used the points-based grading scheme, and 2023, which used the specifications grading scheme. Thus, students' grades were similar for each of the four course offerings regardless of the grading scheme used. Though students' grades were not significantly different, it was easier to connect assessments with mastery of the learning objectives using specifications grading as compared to a points-based grading scheme. Therefore, grades in the courses that used specifications grading may better reflect student learning.

Token Submissions and Assignment Retakes

Specifications grading arguably improves the rigor of the course and requires more work from the students to critically evaluate their mistakes and demonstrate improved learning in assignment retakes. Student effort or amount of work in the course may be partially quantified by looking at the use of tokens. The number of token submissions in 2022 and 2023 are shown in Table 6. Close to half of the token submissions were used for MEQ retakes, just over 20% of them were used for CQ retakes, and the remainder were used for 48-hour extensions to the HW due dates.

Table 6: Number of token submissions

Term	Avg. per student	HW Extension	CQ retake	MEQ retake
Spring 2022 (n = 265)	4.5	85 (32.1%)	66 (24.9%)	114 (43.0%)
Spring 2023 (n = 382)	3.9	109 (28.5%)	77 (20.2%)	196 (51.3%)

Survey Responses to Specifications Grading

Survey Questions

To gauge students' perceptions of the specifications grading scheme, the following questions were asked in online course surveys in the middle of the term and again at the end of the term in the spring 2023 course offering. Responses were kept anonymous.

Please choose your level of agreement with the following statements in Q1-Q4:

Q1: The specifications grading scheme helps me learn in this course.

Q2: The specifications grading scheme is more stressful than a traditional grading scheme.

Q3: The specifications grading scheme gives me confidence to earn my desired grade in this course.

Q4: The specifications grading scheme gives me confidence that I can succeed in future engineering courses.

Q5: Please provide any comments on the specifications grading scheme used in this class.

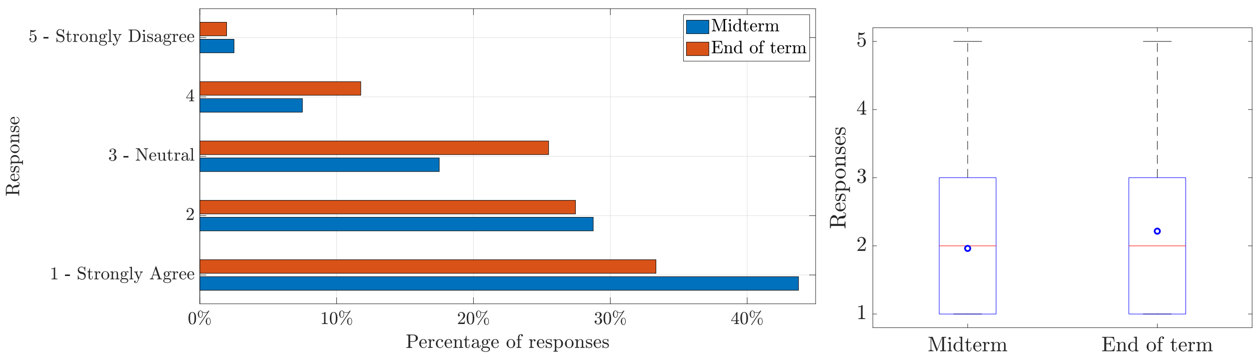
Responses to questions Q1-Q4 were collected on the following Likert scale:

1 - Strongly Agree
2 - Agree
3 - Neutral
4 - Disagree
5 - Strongly Disagree

Responses to Q5 were collected as open-ended written comments.

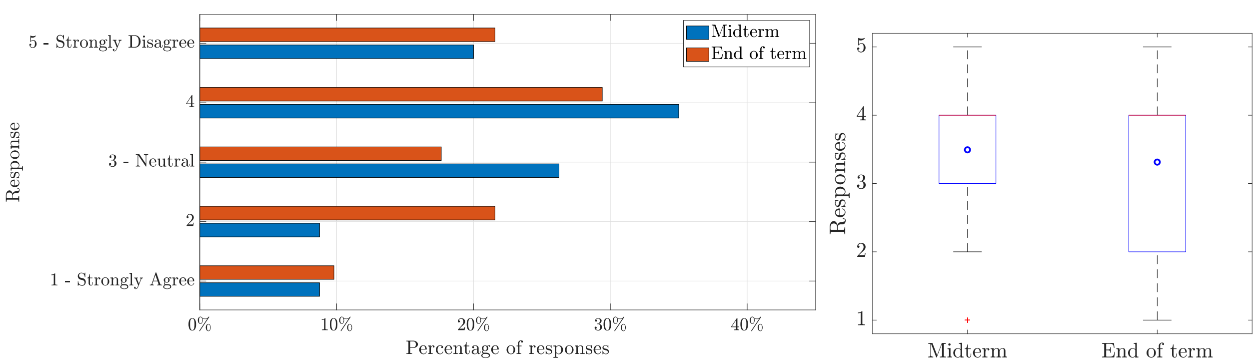
Survey Results

Survey results were analyzed with descriptive statistics, and t-tests were performed to compare responses from the midterm survey to responses from the end of term survey. The quantitative results from questions Q1-Q4 are shown in Figures 2–5, and the responses to the open-ended question Q5 are discussed below.



(a) Responses (b) Statistics ($p = 0.195$).

Figure 2: Responses to Q1: "The specifications grading scheme helps me learn in this course." In (b), the red line indicates the median, the blue circle indicates the mean, the top and bottom edges of the box indicate the 25th and 75th percentiles, and the whiskers extend to data points not considered to be outliers. Outliers, if they exist, are plotted as red +'s. Responses from the midterm survey were compared to those from the end of term survey using a t-test.

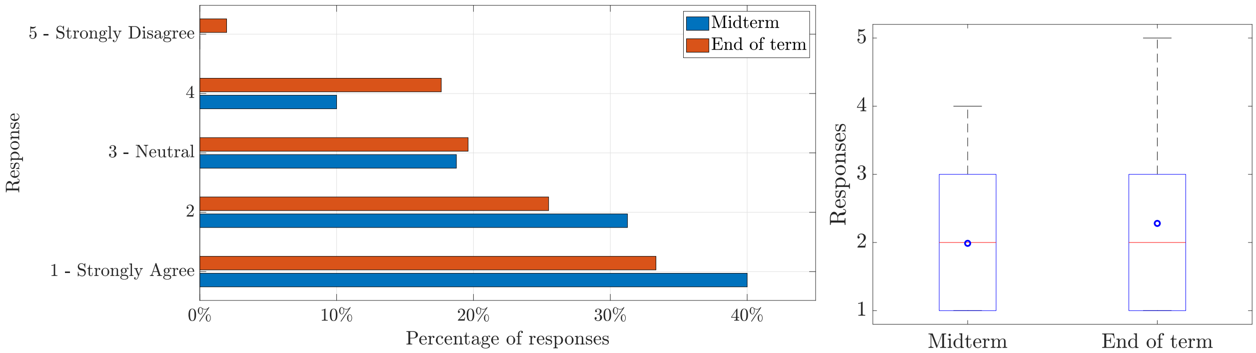


(a) Responses (b) Statistics ($p = 0.416$)

Figure 3: Responses to Q2: "The specifications grading scheme is more stressful than a traditional grading scheme."

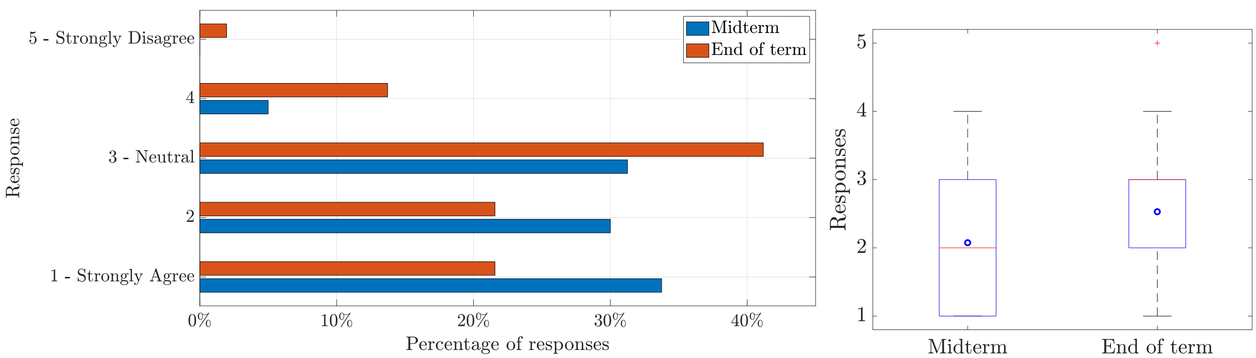
Figure 2 shows that the majority of students agreed or strongly agreed that the specifications grading scheme helped them learn in the course both in the midterm and end of term surveys. The t-test did not show a statistically significant difference between responses in the midterm survey and responses in the end of term survey ($p = 0.195$).

Figure 3 shows that most students did not think that specifications grading was more stressful than a traditional points-based grading scheme. No statistically significant difference was found between responses in the midterm survey and responses in the end of term survey, but the distribution of responses is wider for the end of term survey.



(a) Responses (b) Statistics ($p = 0.133$)

Figure 4: Responses to Q3: "The specifications grading scheme gives me confidence to earn my desired grade in this course."



(a) Responses (b) Statistics ($p = 0.0103$)

Figure 5: Responses to Q4: "The specifications grading scheme gives me confidence that I can succeed in future engineering courses."

Figure 4 shows that most students strongly agreed or agreed that specifications grading gave them confidence to earn their desired grade. Figure 5 shows that at the midterm, almost all of the students who responded to the survey responded that they strongly agreed, agreed, or were neutral that specifications grading gave them confidence to succeed in future engineering courses, with the responses being close to evenly split between those three choices. At the end of the term, a higher percentage of responses were neutral, and more than 10% of responses were "Disagree".

The quantitative data show that students generally appreciated specifications grading, though there were students who responded negatively as well. Student comments in response to Q5 bring out the nuances of these differences, and we discuss the comments and provide quotes from the students' responses below.

Many students liked the specifications grading scheme, particularly its clarity on how grades are determined. The following quotes from six different students highlight this.

- "The specifications grading scheme gives me a clear understanding of what I need to do to pass."
- "I really like the grading scheme because it lets me know how I am progressing with the class."
- "It is new for me but it is easy to understand."
- "The grade tracker helps me keep track of my progress and understand where I should focus my attention on coursework"
- "It's helpful for understanding how to get your desired grade (no nonsensical curves!)."
- "I wish it was used by more classes"

Students also commented how specifications grading changed their motivation or focus towards learning rather than grades:

- "I can learn the contents rather than aiming for a grade."
- "I honestly like this grading scheme because it allows me to really understand the topics."
- "I like the grading scheme. It makes me feel like i can make mistakes and learn from them."
- "It makes me less stressed and allows more room for learning from error."

Several students commented on the "harshness" of specifications grading in that there was no partial credit and no "curving" of the grades, even though there were no significant differences in the grades when comparing the courses that used specifications grading and those that used points-based grading, as described above regarding student performance. This made the specifications grading scheme stressful for several students. The token system was acknowledged as a mechanism that eased some stress. Retake opportunities were essential for most students to earn their desired grades given the high standards set to pass assignments, and a significant number of tokens were used for each assignment bundle, as shown in Table 6. Some students wanted more retake opportunities. These sentiments are exemplified in the following quotes from nine different students.

- "The specifications grading scheme is great in many respects, but does not allow for a curve."
- "The grading scheme sets very high standards but can be somewhat forgiving with token system"
- "Specifics [sic] grading particularly for exams seems more stressful"
- "It is less forgiving for when you have a bad test day."
- "The retakes are helpful, but the limit of retakes adds so much stress."
- "I think it would be fair if it wasn't so strict on what is considered to be a high pass"
- "[The token system] helps relieve stress, especially since it lets us have extra time and attempts."
- "I personally rely on doing well on the final [exam] and for my grade to "balance out." So it was stressful knowing that I had to do well on everything. But I do think that is how it should be. Ideally speaking, I should be doing well on everything because I should understand everything. I do believe this is a me problem though."
- "In my opinion, the specifications grading scheme would be more effective if it were more forgiving as opposed to being extremely binary (pass/fail). I think if exams were graded on a scale of more

than just two points, the system would be fairer and more encouraging for students to do well and earn the grade they want."

The overall conflicted sentiment that some students had is well described by one student in the following quote:

- "In my opinion, this grading scheme is a double edged sword. Yes, I find it less stressful but it feels like an all or nothing situation sometimes. If you forget a single concept, you basically automatically get a [low pass]. Forget a single step and you're essentially forced to use a token. No partial credit at all. Overall, it's a good system though."

Discussion on Benefits and Challenges of Specifications Grading

The specifications grading scheme enhances the rigor of the course, the metacognition of the students, and ultimately the students' demonstration of the learning objectives. It reduces the number and severity of high-stakes assignments and encourages students who initially perform poorly to be able to understand their mistakes and correct them in a retake. Specifications grading also, arguably, better exposes engineering students to how their work will be evaluated in their future careers, as either "good enough" or "needs revision."

The quantitative survey results show that students generally felt that the specifications grading scheme helped them learn, was not more stressful than a points-based grading scheme, and gave them confidence to earn their desired grade in the course and succeed in future engineering courses. Some of the discrepancy between the responses at the midterm and at the end of the term may be due to differences in who responded to the survey, since 82.5% of enrolled students completed the midterm survey, but only 52.6% of enrolled students completed the end of term survey, as shown in Table 1.

Though there was no significant difference in students' grades through the four course offerings, student engagement seemed to increase in the courses that used specifications grading. It seemed, without explicitly collecting empirical evidence, that significantly more students attended discussion sections and office hours with both the instructor and teaching assistant in the courses that used specifications grading. This is likely due to the motivation of earning tokens and better understanding course material to improve their grades in assignment retakes.

The token system is a critical part of the specifications grading scheme that enables students to retake assignments to improve their learning and grades and encourages students to participate in activities that help their learning (e.g., attend discussion sections or complete assignments like a syllabus quiz) without needing to include those activities in the grading scheme (e.g., giving points for participation and attendance). This allows grades to better reflect students' learning while still motivating students to employ good learning practices. As an example opportunity to earn tokens, students earn 3 tokens for completing the "How I earned an A in this class" assignment. This assignment is recommended in [11] and serves multiple purposes: It offers students an opportunity to earn tokens while also having students examine the course syllabus and grading scheme to understand and plan how to earn their desired grade. This assignment is important for students to get acquainted with the specifications grading scheme, which may be very different from traditional grading schemes they are used to, and it shows students the advantages of a specifications grading scheme, namely that it clearly provides criteria from the beginning of the course and in each assignment regarding what needs to be achieved to earn a particular grade and that there are opportunities to retake assignments to improve grades. The assignment also supports students' metacognition regarding how they learn and helps them plan ahead to be successful in the course.

Student Buy-In and Other Challenges

As has been documented in several other implementations of specifications grading in the literature, some student reactions were mixed. For example, students initially see specifications grading as harsh because there is no partial credit. This is understandable as specifications grading is unfamiliar and differs from other traditional grading schemes. Therefore, working towards student buy-in is important, including motivating the purpose of the grading scheme, a clear description of how it works, and highlighting the opportunities for students to improve their grades (i.e., demonstrate mastery) through retakes or resubmissions that traditional grading schemes may not allow. Clearly stating these things in the course syllabus, having students plan out their learning based on the grading scheme in the "How I earned an A in this class" assignment, and reiterating the purpose and advantages of specifications grading throughout the course, particularly at the beginning, middle, and end, was found to be helpful. Moreover, providing class time and ongoing asynchronous discussion board posts where students can ask questions and get quick answers on the grading scheme was also helpful.

Challenges to implementing specifications grading include the initial work required to make the transition from a points-based grading scheme, buy-in from colleagues and students, and managing the retakes and additional grading. Transitioning to specifications grading may require redesigning assignments to measure particular learning objectives and creating extra questions or assignments for retakes opportunities. Fortunately, these only affect the transition to specifications grading and are less significant once specifications grading has been employed multiple times. Though assignment retakes created roughly 1.5-2 times the amount of assignments to grade, it was much faster to grade the free response MEQ problems as "High Pass," "Low Pass," or "Needs Revision" rather than determining how to award partial credit. Thus, the time spent grading may be less than in a traditional points-based grading scheme. Logistically keeping track of students' tokens and token submissions takes time, but there are ways to make this easier, such as including a "dummy" score in the course learning management system to keep track of how many tokens students have and creating an electronic form that students complete to submit tokens that automatically populates a spreadsheet to keep track of token submissions. Moreover, limiting the number of tokens opportunities for retaking assignments helps manage the grading load for the instructional team and incentivizes students to plan out their work to earn a particular grade and to still work hard and study for first attempts of assignments.

Specifications grading makes grading "fairer" in that grades are based on an individual student's demonstration of the learning objectives and do not depend on the performance of another student. However, for various reasons, some students may not take advantage of retake opportunities or interact with the instructional team to discuss course concepts they are struggling with or how to improve their work. Students' help-seeking and other behaviors are well-studied phenomena that should be considered and appropriately addressed in the context of any course grading scheme.

Conclusion

In this work, we described and evaluated a specifications grading scheme used in an engineering dynamics course as compared to a traditional points-based grading scheme. We found that specifications grading has the following benefits: improved students' metacognition of their own learning, improved students' mastery of the course learning objectives, reduced high-stakes nature of assignments where students "cram" to perform well on an exam and then forget the material or are not motivated to revisit the material they did not initially master, motivated students to participate in activities to improve their learning, and reduced grading time (e.g., hunting for opportunities to give partial credit). Moreover, students reported that the specifications grading scheme helped them learn in the course and gave them confidence to earn their desired grade.

Future work will include formally measuring and analyzing what impact, if any, grading schemes have on attendance, participation, engagement with instructors and peers (i.e., help-seeking behavior). Additionally, further analysis of the token system, including which students were submitting tokens, how many tokens they earned and submitted, and which assignments they revised and resubmitted will be performed. This analysis will help to inform how to encourage and enable all students to take advantage of the retake opportunities and how to promote metacognition.

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Appendix - Course Learning Objectives

By the end of the course, students should be able to...

1. determine, using kinematic relations, the motion, distance traveled, and velocity of
   a) a single particle.
   b) a system of particles.
   c) a rigid body for 2D (planar) and 3D motion.
2. translate polar coordinates to 3-dimensional Cartesian coordinates.
3. take the derivative of a rotating unit vector.
4. translate rotating vectors to fixed coordinate system vectors at a given instant in time.
5. define correct direction for the force of friction.
6. apply the "no slip" condition and understand how it relates to friction.
7. apply physical constraints to reduce number of unknown variables in a system of equations.
8. define body-fixed coordinate system for 3D motion of a rigid body.
9. draw free body diagrams and equate forces and motion (i.e., apply Newton's 2nd Law) for
   a) a single particle.
   b) a system of particles.
   c) a rigid body.

10. calculate the work done on/by, and the energy of,
    a) a single particle.
    b) a system of particles.
    c) a rigid body.
11. apply the work and energy principle to analyze motion of
    a) a single particle.
    b) a system of particles.
    c) a rigid body.
12. calculate linear and angular momentum of
    a) a single particle
    b) a system of particles.
    c) a rigid body.
13. apply impulse and momentum techniques (and draw impulse-momentum diagrams) to analyze motion of
    a) a single particle.
    b) a system of particles.
    c) a rigid body.