A Fluency-Based Assessment and Grading System for Improving Student Engagement and Motivation

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Yeow Siow received his B.S., M.S., and Ph.D. from Michigan Technological University where he began his teaching career. He then joined Navistar's thermal-fluids systems group as a senior engineer, and later brought his real-world expertise back into the classroom at Purdue University Northwest. Since 2013 he has been teaching at UIC where he enjoys discovering advances in engineering education, particularly innovative pedagogy, equitable assessment, and instructional technology integration.

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Background and Motivation

Having spent several years in the field as an engineer, I have discovered firsthand that an impactful problem solver is one who always engages themselves with not only the tasks at hand, but also the community; one who has a sustained drive to reach a goal; and one who effectively communicates ideas while being critical of their own work. In other words, it goes far beyond technical ability. A typical undergraduate engineering course would often focus solely on student knowledge and skill development, and rarely on learner motivation and engagement. In this study, I set out to overhaul a core mechanical engineering course, particularly the assessment and grading structure in its entirety, and investigate how the new grading system impacts student motivation and engagement compared to conventional engineering courses.

Introduction and Concise Literature Review

Student assessment is a necessary but often dreaded part of our job as engineering educators. We are required to assign a letter grade to each student when the term ends, and we often find ourselves using the same process we have experienced as a student. Homework, quizzes and exams have been the cornerstone of deciding student grades, and if the class-wide grade distribution does not fit a certain expectation, we perform a corrective maneuver called curving. At the institution level, policies such as final exam schedule and rules further reinforce the perception that the age-old process we have been using is sacred and not to be tampered with. Nevertheless, many educators and researchers dare to challenge the norms and innovate.

John Dewey [1], a pioneering philosopher and education reformer, advocated for student-centered pedagogy that evolved into problem-based learning (PBL), a well-adopted method of teaching and assessment among engineering courses today. Kilpatrick [2], a student of Dewey, developed what is known as project-based learning (PjBL) and assessment where students would demonstrate their knowledge and skills through solving real-world problems. Chen et al. [3] conducted a comprehensive literature review of PBL and PjBL in engineering education in the past twenty years, and noted these methods' wide adoption in engineering courses and curricula, but also cautioned that appropriate assessment methods should be carefully selected to effectively measure student learning and, in particular, transferable skills.

Learning by reflection, pioneered by Schön [4] and further developed by researchers such as Boud and Walker [5] and Moon [6], is a process by which students use their own experiences to achieve understanding, generate insight and develop further action. More recently, Olds [7], Thurner et al. [8], and Williams [9] were among the many researchers who studied reflection as assessment. An important conclusion from these findings is that reflective writing can be an effective way to assess student learning and growth.

PBL, PjBL and reflection are examples of innovative methods of knowledge discovery or skill development, but also unconventional methods of student assessment.

On a systems level, limited research has been done on new grading systems designed specifically for engineering education. Several nonconventional grading systems in general higher education have been proposed, and some have been adapted to engineering. Standards-based grading (SBG), mastery-based grading (MBG) and specifications grading are student assessment frameworks that fit the competency-based education (CBE) ideals [10]. A specific adaptation of MBG in engineering is called Conceptual Fluency Approach (CFA) by Hamel and Eagle [11], for a thermodynamics course where students received multiple opportunities to improve their understanding (and grade) by requesting partial credits; CFA was a result of equitable assessment and inclusive teaching practice.

SBG, MBG, specifications grading and CFA are examples of grading system reform. These systems put learners first, and focus on specific technical or professional skills to be attained by students. Each system has their benefits and challenges. MBG, for example, requires flexibility and significant resources in grading and providing feedback. SBG requires a set of well-defined learning objectives to be successful.

While the effectiveness of these alternative grading systems has been studied, most work has focused on student learning outcomes. Few researchers have focused on how they affect student engagement and motivation. This paper reports my latest effort in studying a new CBE-centric, equity-minded grading system, on how it impacts student engagement and motivation instead of learning outcomes.

Li [12] conducted a comprehensive review of literature on the types of, and ways to measure, cognitive engagement of students. Smith et al. [13] offers concrete evidence to advocate that student engagement, not the course learning outcomes, should be the focus of higher education, from the course level (instructor pedagogies) to program or institution level. This work informed my research question in that student engagement is an appropriate outcome to measure.

To measure student motivation and engagement, a self-reporting instrument was developed referencing the works by Heckhausen et al. [14] as well as Diefes-Dux and Cruz Castro [15].

FAS: Fluency-Based Assessment System

Guided by backward design and a growth mindset, FAS is, at its core, an evolutionary coalescence of efforts-based assessment, assessment by reflection, PBL, SBG, MBG and CFA; the level of *fluency* is then mapped to the institution's letter grades by defining a clear set of expectations. Under FAS, each student entering the course shares the same, zero baseline, and begins to earn "fluency points" (FPs) as the term progresses. Each FP earned represents successful and on-time completion of a task. "Success" means meeting a specific set of expectations, or rubrics. In this particular implementation, tasks consist of three categories: Video Lecture Reflection (VLR), In-Class Practice (ICP), and Projects.

VLR is a mechanism for students to be intentional while watching a prerecorded (and heavily edited) lecture video prior to a class meeting. Individually, students take notes of the video content and, more importantly, reflect on their own learning in the notes. Each VLR is worth one FP and is due by the start time of the next class session. VLR is graded using a binary rubric published in the assignment document.

For ICP, during class students are presented with a real-world problem related to the VLR content. The problem is usually a real-life scenario and loosely defined, with several prompts for goal setting and whole-class discussion. Students then work in small teams to produce consensus and share their work with the class, and I often offer an intervention before deliberation. I typically guide the class through the thought process while keeping it open-ended. Each ICP is worth one FP and is due by the next class. Similar to VLR, ICP is graded using a binary rubric.

While flipping my classroom I divided the entire lecture content into thirty four modules, each represented by a VLR-ICP pair. A total of 34 VLRs and 34 ICPs are available for the entire term.

Project is a way to let students demonstrate, often authentically, and reflect their learning while working on a real-life problem. All projects are open-ended and open-resource, with a focus on effective delivery of student work (video or written format) and rationale of the choices made in their analysis. Five projects are made available, and each project is worth six FPs based on the following three fluency groups: Technical rigor, professionalism, and rationale-reflection. Each group is worth up to two FPs, and specific expectations for each fluency group depends on the nature and description of the project. Appendix B shows the rubric I use for a video-based project where students are tasked with experimentally determining the damping coefficient of a structure and performing a theoretical analysis.

All five projects have the same fluency groups, and they reflect the value set forth earlier in this paper. It is worth noting that the project rubric includes, and exceeds, the ABET outcomes for this course to achieve rigor.

To tie student fluency to the University of Illinois Chicago's letter grade system, I use a reference map based on well-defined expectations and assumptions. In the ME 308 Mechanical Vibrations implementation, shown in Appendix C, to pass the course with a D grade a student must successfully complete all 34 VLRs and 34 ICPs, i.e., having earned 68 FPs. To achieve a C, B or A grade, a student must successfully complete one, two, or three projects, respectively.

Achieving an A grade, under this mapping, means that the student has demonstrated consistent effort throughout the semester and shown fluency in tackling at least three real-world problems.

In addition to pre-recorded lecture videos and live classes, a discussion forum is set up to establish a learning community. Students can anonymously post questions and help provide answers collectively.

Research Question and Method

To answer the research question, "how does FAS impact student motivation and engagement," a self-reporting questionnaire has been developed and administered at the end of the Spring 2023 semester. The instrument, presented in Appendix A, consists of 19 Likert-scale items and two open-ended questions. The same instrument is administered to each participant twice: One for ME 308, and one for an ME course using a conventional grading system.

Results

The results are shown in Figures 1-3. A total of 25 respondents were recorded for FAS, and 20 for conventional. The graphs include both the mean and standard deviation values.

In general, the results revealed that FAS appears to have a positive impact on student motivation and engagement. However, the large standard deviation observed in some of the questions (for both FAS and conventional) suggests that there is no one-size-fits-all approach to assessment.

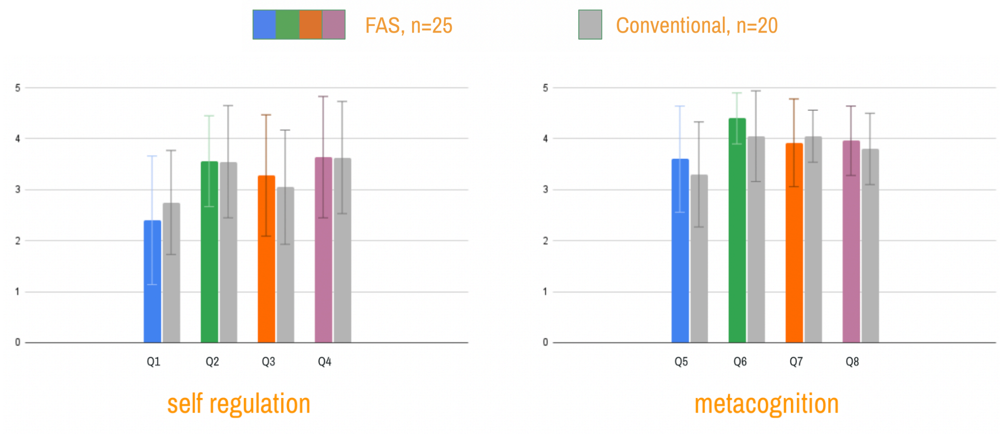

Figure 1. Results: self regulation and metacognition.

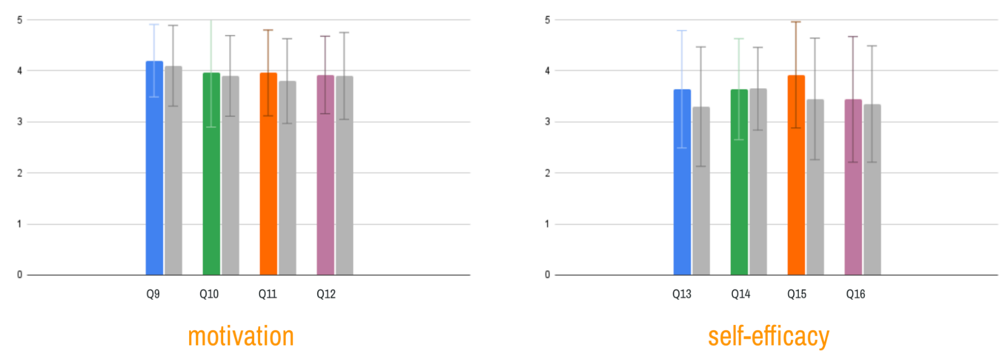

Figure 2. Results: motivation and self-efficacy.

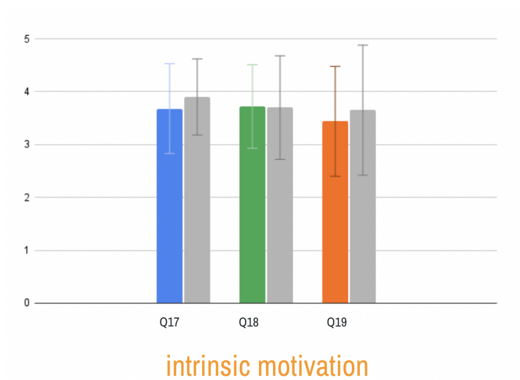

Figure 3. Results: intrinsic motivation.

In addition to the Likert-scale questions, participants were asked to answer two open-ended questions regarding the FAS intervention course:

1. Can you describe an assessment item you most enjoyed or found most stimulating? And why was this?
2. Compared to the conventional grading system in other engineering courses, how has the fluency system used in this course impacted your learning experience so far?

The overall responses to these two questions are encouraging, and may provide further insight into why and when FAS may be a better choice. Some highlights include:

> *Projects…keep me engaged and don't take up an insane amount of time.*
>
> *I noticed that I worry less about the grade and more about completing the tasks…which has helped me retain more information as I learn more.*
>
> *It allows me to track where I am in the class which makes me more motivated to do my assignments on time.*
>
> *It motivates me to do more assignments to earn a better grade. Many traditionally done courses have various weighting systems and it actually punishes me sometimes.*
>
> *...fluency system is amazing for my style of learning. I enjoy fast lessons since I tend to have a short attention span.*

Discussion and Conclusion

The assessment and grading system of a core Mechanical Engineering course has been completely overhauled, and a research study has been conducted to investigate the impact of the new grading system on student motivation and engagement.

While the research work is focused on the Spring 2023 semester, FAS in its current form has been in use in my ME 308 course since Fall 2021. Anecdotally students in past semesters overwhelmingly preferred FAS over conventional grading systems. The FAS rubric-based grading process, as my past teaching assistants have noted, was more efficient and transparent than grading conventional quizzes and tests. Additionally, by removing the need to grade student work against a standard solution (as often required by conventional exams), FAS allows TAs to provide thoughtful and meaningful feedback to students.

The body of work in student assessment in engineering education is extensive. While there is strong evidence of benefits in unconventional assessment or grading methods, the impact has largely been measured by using student achievement of learning outcomes as a metric. Overall course grade is a common choice among researchers and scholars when reporting those data. Some researchers have instead focused on student behavior, intrinsic motivation or other traits in relation to assessment. I hope to continue to contribute to the latter with my current research.

As a follow-up study, I plan to survey students who were enrolled in the same course in Fall 2023. Most of these students are currently (Spring 2024) in their penultimate or ultimate semester. The follow-up will provide insight into the longer-lasting impact of FAS.

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Appendix A: Measures of Motivation and Engagement

Coding: 5-level Likert scale, 1 = strongly disagree, 5 = strongly agree

Section	Items
Self Regulation	1. The frequency of assignments helps keep me motivated 2. The frequency of assignments helps me learn the course material 3. The frequency of assignments makes me look forward to the next topic 4. The frequency of assignments helps me stay organized
Metacognition	5. When I do an assignment, I think about how I learn in addition to what I learn 6. When I do an assignment, I try to relate recent classroom discussion to the problem I'm solving 7. When I do an assignment, I recall my past mistakes and learn from them 8. When I do an assignment, I try to improve myself
Motivation	9. While solving assignment problems, I draw a parallel with what I see or experience in real life 10. The assignments help me appreciate the relevance of what I'm learning 11. The assignments help me understand the dependency between assumptions (i.e., idealization) and a solution 12. The assignments make me realize the many different ways of solving real-life problems
Self-efficacy	13. I know I can earn enough points to achieve the grade I want in this class 14. Every time I successfully earn a point, I feel more confident about myself 15. I know exactly what it takes to score well in each assignment 16. I know exactly where I stand in terms of course grade
Growth mindset, intrinsic motivation	17. I have been able to prove to myself that I can improve and do better in this class 18. I know that my effort in this class will not go to waste 19. I am rewarded by demonstrating what I know

Appendix B: FAS Project Rubric

	Fluency Level (and FP Earned)		
Rubric Group	2	1	0
Technical Rigor	Appropriate structure is used to illustrate the vibration type; experiment is well constructed; observed data accurately collected and plotted; theoretical analysis is accurate	Some obvious details missing	Farfetched, or missing most details, or missing altogether
Professionalism	Video has good quality visuals, clear audio, smooth "flow" and editing; educational and fun; a joy to watch	Some issues with visuals, audio, and/or production relevance	Can't make out most visuals, barely audible; or production unrelated to project topic
Rationale-Reflection	Thoughtful and authentic; a comparison of experiment and theory is clearly made; acknowledges limitations/inaccuracy and suggests future (self-)improvements	Insubstantial or vague	Missing altogether

Appendix C: FAS Mapping to Letter Grades

Total FP Earned	Letter Grade	Fluency Mapping
≥ 86	A	Successfully completed all VLRs and ICPs, plus three projects
80 - 82	B	Successfully completed all VLRs and ICPs, plus two projects
74 - 76	C	Successfully completed all VLRs and ICPs, plus one project
68 - 70	D (passing)	Successfully completed all VLRs and ICPs