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Instructor Experiences Implementing Two Engineering Graphics Courses using Mastery-Based Grading and Project-Based Learning

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Abstract

This research paper presents the pedagogical approach and some common themes of faculty reflections on the implementation of two engineering graphics courses that utilize mastery-based grading and project-based learning. Mastery learning is based on the philosophical foundation that any student can learn any topic given enough time and support, rejecting the premise of learning as linear. Mastery-based grading is an assessment methodology that provides students a non-punitive way to practice these topics with feedback from their instructor. Mastery-based grading has been shown to have largely positive impacts on student learning by being non-punitive in nature and providing students multiple opportunities to demonstrate mastery of a subject. Mastery-based grading also increases students' achievement of learning outcomes, since the mastery structure requires students to fully understand and apply concepts before moving on to other learning objectives, unlike traditional numerical grading. This style of grading works well for engineering graphics courses because the generation of engineering graphics is a skill that develops and is retained through repeated practice. By requiring students to practice a skill until it is mastered, the amount that each student will learn and retain should increase. The flexibility of a non-linear learning trajectory means it can adapt to the needs of individual students, a significant move toward educational equity. A project-based approach to engineering graphics education also provides increased opportunity for student engagement, with projects tailored to students' lives and interests, and exploratory approaches prompt more critical thinking throughout the learning experience, rather than regurgitation.

This paper discusses the development and implementation of mastery-based and project-based courses at two different institutions. The first course is a required, first-year, 3 credit lecture and laboratory course using Onshape taught by one faculty member at a mid-sized, private institution that transitioned from a traditional grading scheme. The second course is a required, first-year, 1-credit laboratory course using AutoCAD taught by a team of three faculty members at a large, public, majority-minority institution. First, the implementation of the two courses in question will be compared by comparing the syllabi of the courses. Then, a thematic analysis of reflections provided by the four faculty involved in teaching and developing the courses will be presented. The analysis will compare the experiences of each faculty member and how the differing implementation of the courses may have affected those experiences. The combination of these experiences and reflections will give insight into the variety of ways that mastery-based grading and project-based learning can be implemented. The insights provided in the faculty reflections highlight important considerations for those implementing mastery-based grading and project-based learning in engineering graphics courses.

Introduction

Design classes are an important part of the engineering curriculum because they excite students who are interested in the creative aspects of engineering, and they teach an important skill that professional engineers need to creatively solve problems in their jobs. An important aspect of design is engineering graphics as it is a necessary skill to model a design and communicate that design using engineering drawings. Software used to generate 3D models and engineering drawings has been taught using a variety of methods documented in research literature, including training videos [1], a flipped classroom approach [2], industry-supplied videos [3], and web-based interactive activities [4], [5]. Each of these methods were found to have varying effects on student learning outcomes. In [2], it was found that there was no significant change in grades when the course was switched to a flipped classroom approach while [3] found that industry-supplied Computer-Aided Design (CAD) instruction videos were effective in teaching important engineering skills. [4] and [5] found that using web-based games to introduce and practice concepts in engineering graphics was effective.

In addition, non-traditional pedagogical approaches such as project-based learning (PBL) [6], [7], [8] and mastery-based grading (MBG) [9], [10] have also be used to improve how engineering graphics is taught. PBL has been used extensively in engineering graphics courses in various forms involving team design-build projects [6], [11], [12], [13], [14], 3D printing [7], [15], and socio-technical and culturally relevant projects [16], [17], [18]. In these studies, projects have been shown to help students engage with the course material and provide additional ways to practice engineering graphics skills. As a result, students have found that the projects helped them to feel more confident in their skills and perform better in the class overall [6], [19]. The projects also tapped into students' creative side, something that they had not previously associated with engineering [11]. More recently, mastery-based learning (MBL) and MBG have also been implemented in engineering graphics courses in various ways including rapid feedback-resubmission cycles [5], [20], [21], diagnostic pre- and post-tests [9], [10], and activity self-checks with formative feedback [22]. In these studies, MBG has been shown to improve students' understanding of course content [20], as repeated submissions with feedback improves students' skills and understanding of course material [5]. Many studies have been done studying the effects of these methods on student outcomes, but not as much literature documents how implementing these methods and pedagogies affects faculty [14], [21], [23].

This paper will share a thematic analysis of the reflections of four faculty who have implemented MBG and PBL in a first-year engineering graphics course at their respective universities. These reflections provide insights into the process of and challenges faced while implementing an engineering graphics course using both pedagogies. The reflections also show the similarities and differences in faculty experience, as the faculty are located at two different universities, a large public university and a mid-sized private university, and have different degrees of past experience with MBG and PBL.

Background

Mastery-Based Learning

MBL is based on the concept that given enough time and quality instruction, any student can achieve mastery of any material being taught to them [24]. While grading normally is a method of summative assessment intended to evaluate how well course material has been learned, MBG is intended as a method of formative assessment to facilitate continuous improvement. MBG contributes to MBL, as students receive feedback on assessments related to the course learning outcomes. In this framework, students repeatedly submit and receive feedback on their work until they have reached completion through demonstrating mastery of the material covered in the assignments. This process of repeated formative assessment can be applied to any kind of assignment including exams, projects, and presentations, types of evaluation instruments that are normally used as methods of summative assessment [25]. MBG has been shown to be a more equitable form of grading. When implemented, it has been shown to narrow the achievement gap between students of different ethnic and socioeconomic backgrounds [26], [27]. Research has also shown that students generally liked MBG [21], [28] and perceived that they learned better with MBG [25], [27].

Within courses on engineering graphics and design, variations on MBG have been used. In these implementations, faculty have implemented a rapid feedback-submission cycle on course assignments so that students can learn from their mistakes and earn back some or all the points they lost in the previous submission [5], [20]. In some cases, this was implemented within an online platform meant to gamify the learning process [5], [29]. In other cases, MBG was implemented as formative feedback within active learning modules [10], [30]. In each of these implementations, students have shown improved performance overall and an increased perception of learning due to having repeated submissions. Because MBG relies on a repeated submission-feedback cycle, it works well for engineering graphics and design courses, since the material covered in these courses, which usually includes spatial visualization and using 3D modeling software, requires repeated practice to learn. However, some of these variations lack the non-punitive nature originally inherent in MBG since students are only able to earn back some of the points they originally lost. This discrepancy begs the question of how well MBG and its philosophical foundations are understood within the engineering graphics community. Research should explore why these variations are employed by different instructors and the effects they have on the student learning experience.

Project-Based Learning

PBL is a popular pedagogy used in engineering courses, since it emulates what these students will need to be able to do in their future engineering careers [31]. Research has shown that the use of PBL has increased students' confidence in their ability to apply engineering graphics skills [19]. Additionally, students were able to expand their perceptions of the scope of work required to do engineering projects beyond the math and science usually taught in engineering courses [8], [11]. Class projects also create an opportunity to include aspects of the students' identities through projects that incorporate inspiration from their cultures and socio-technical community-based challenges [16], [17], [18]. Incorporating culture and socio-technical challenges in projects helps students to engage with engineering in a way that is authentic to their own identities. This helps them see themselves as engineers by increasing their sense of belonging in the engineering community while increasing their sense of value and respect for other students' cultures [17].

Within engineering graphics and design courses, PBL has also been used to incorporate a manufacturing or build component into team design projects. By incorporating a build component within a graphics and design class, students experience the realization of a physical product and make connections between engineering design and manufacturing challenges [7],

[11], [14], [31]. This has been shown to increase interest in engineering as it demonstrates to students how engineering requires creativity and non-technical knowledge while developing their teamwork abilities through the design and build of a product. In addition to increasing student engagement with the material, this also requires students to think outside of what they were taught in class, thus requiring them to use critical thinking and creativity to engage with the course material [11]. This results in increased engagement with the material, use of creative thinking and problem-solving skills, and understanding of how design work relates to manufacturing and build processes [11].

Methods

This paper came about because Samantha (who will be referred to as Sam) and Corin (who will be referred to as Corey) realized that they were both planning to teach engineering graphics classes using MBG and PBL for the first time at two different universities during the same academic term. It was surprising that both instructors were planning to do the same style of class independently. Therefore, we were interested in comparing our experiences teaching these classes to find similarities and differences. Because each instructor's experience is dependent on the class that they were teaching, the two courses in question will be compared. Using the syllabi for the courses, the course logistics, type and number of assignments, grading scheme, and feedback mechanisms will be compared for similarities and differences. The comparison of these aspects of the two courses will be used to give context for the instructors' reported experiences.

The second part of this paper will present a thematic analysis of each instructor's reflections on their experiences teaching the classes. The reflections were written independently and were guided by loosely structured reflection questions. The questions asked the authors about their teaching experience in general and with MBG and PBL to provide their background prior to teaching the engineering graphics class. They also included questions about their experience teaching the class related to what worked well and what did not work, if teaching the class was made easier or harder using these pedagogies, how they engaged with students related to the pedagogies, how students responded to the pedagogies, and if they would change anything given the chance to teach this class again.

Using both the course syllabi and themes from the instructors' reflections, the authors will draw comparisons between their experiences and reveal challenges that are unique because of the context of the class. Additionally, similarities in the faculty experience despite differences in the courses they were teaching will also be highlighted. By highlighting both similarities and differences in the faculty experiences, the variety of experiences that faculty may have when implementing an engineering graphics class using MBG and PBL will be showcased.

Course Comparison

The four authors of this paper collectively taught four sections of two engineering graphics courses using MBG and PBL in the fall term at their respective institutions in 2024. The first course was taught by Sam at a mid-sized, private university. The second course was taught by Corey, Gustavo, and Shardul in three sections offered at a large, public university. The structure of these two courses, as taken from their syllabi, are given in Table 1.

Table 1: Comparison of Course Structures

Course	Department	Credits	Course Level	Class type	Sections	Instructors	Software	Total Enrollment Across Sections
1	Mechanical Engineering	3	First-year	Required	2	1	Onshape	42
2	Civil Engineering	1	First-year	Required	3	3	AutoCAD	80

As seen in Table 1, the two engineering courses have many differences that will affect how they were implemented and the experience of the instructors when developing and teaching these courses. These variations in the courses that were taught by the authors will affect their experiences teaching this course. For example, Course 2 had three instructors each teaching a section. One of the instructors took on the role of coordinator for all the sections. This makes the coordinator's experience different because they had to manage all three sections of the course in addition to teaching one of them. In contrast, Course 1 only had one instructor who taught both sections that were offered.

Assignments

Each course, due to their differing purposes for their respective degree programs, had different assignments. Course 1 had three sets of assignments: 21 in-class activities, 6 homework assignments, and a team project with 4 milestones that need to be submitted. The in-class activities and home assignments could all be submitted up to three times each. Each submission was graded using a points-based system with extensive feedback provided by the instructor. Students then used the feedback to correct any errors and resubmit the assignment to be regraded. The instructor encouraged students to resubmit their assignments soon after receiving feedback in the syllabus to reduce the accumulation of work at the end of the term. The team project consisted of 4 different submissions including a product selection worksheet, a concept review worksheet, a preliminary design review portfolio, and a critical design review portfolio. The project milestones were due at various points throughout the term.

In contrast, Course 2 was entirely project-based. The assignments in the course consisted of 3 projects with multiple parts in each, as shown in Table 2. Each project part submission received a "complete" or "incomplete" with feedback describing what they should improve, and students kept resubmitting until they completed the part by demonstrating mastery of the skills being evaluated. There was no limit to the number of times any project part could be submitted, and there were no deadlines in the course other than the last day of submission at the end of the semester.

Table 2: Project and Grade Breakdown for Course 2

Project	Part	Grade Earned (Upon Completion of project part)
1) Architectural Floor Plan Drawing of an area in ECST	a) 2D Hand Drafting	C-
	b) 2D AutoCAD Drafting	C
2) Mechanical Drawing of an Object You Select	a) 2D Hand Drafting	C+
	b) 2D AutoCAD Drafting	B-
	c) 3D Inventor Modeling	B
	d) Scaling and 3D Printing	B+
3) Survey Mapping of an area of the Cal State LA Campus	a) AutoCAD Plan Mapping	A-
	b) AutoCAD Contour Mapping	A

Grading Scheme

In Course 1, the assignments were graded using a MBG approach, where the points earned were assigned based on demonstration of mastery of the related skills rather than based on how many points each mistake in the problem is worth. Each assignment had a number of points associated with it, and the overall course grade was determined by the grade breakdown given in Table 3. These points were assigned on a 3-point scale, where 3 points equated to “mastery”, 2 points equated to “near mastery”, 1 point equated to “progressing”, and 0 points meant that the instructor was unable to evaluate the submission. All assignments were graded using this 3-point scale, and detailed comments were provided on what aspects of the assignment the student still needed to work on to achieve mastery on the assessed skills. In-class assignments were graded as “complete” or “incomplete”, with students earning a “complete” if they completed all aspects of the assignments. As seen in Table 3, the team project was most heavily weighted in the final grade.

Table 3: Grade breakdown based on category for Course 1

Assignment Category	Percentage of Total Grade
In-class Assignments	25%
Homework	35%
Team Project	40%

In Course 2, both the project parts and the overall course were graded using a MBG approach. Each project part was marked as completed if they demonstrated mastery on the assigned work. Students’ final grades were then decided based on how many project parts were completed over the course of the academic term as shown in Table 2. This meant that if students completed all project parts, then they would earn an A. Thus, this class did not utilize any percentages or points in either the assignments or the final grade, as in Course 1, only a check for mastery.

Feedback Mechanisms

An important aspect of all courses with MBG is the feedback mechanism used to communicate feedback on assignments to students. Both courses relied heavily on Canvas as the main learning management system and the main method of communication. Course 2 explicitly highlighted multiple ways that the teaching team would communicate with the students, including during and around class time, via email, during student hours (what the instructors called their office hours), and via a Discord channel. The syllabus emphasized that the instructors would communicate frequently through Canvas announcements and respond to emails as quickly as possible. They also emphasized that students could schedule additional time to meet with instructors outside of the set student hours depending on the instructors' schedules.

For Course 1, the instructor gave a clear schedule of how quickly they would respond to emails or messages through Canvas and offered students the ability to schedule in-person or online office hours outside of the scheduled office hours. The syllabus also included information about how to submit assignments through Canvas, through Onshape's online class portal, and the timeline for feedback. The syllabus explicitly stated that Sam would return feedback within 5 working days so students could use that feedback when they worked on their subsequent submissions.

Discussion

The reflections written independently by the four authors indicate several shared experiences related to the amount of time required to run a class using MBG and PBL. One reflection all four authors shared, no matter their experience level, was that implementing MBG was very time consuming. Part of the reason for the time commitment was that both courses offered a resubmission process that is characteristic of MBG for some or all their assignments, and the repeated submissions took a long time to grade - even with the ISAs supporting this work in Course 2.

In Course 1, Sam was worried about "balancing the mastery-based aspects of the class with the amount of work that [she] could feasibly do." Sam "found that PBL was not difficult to implement because it was already a component of the class before [she] modified it" so she only had to make modifications to improve upon the previous project version. However, Sam was concerned about having enough time to grade resubmissions on each project component and so chose to not allow resubmissions on the project components. For Course 2, Corey, Gustavo, and Shardul found development of the PBL aspects of the course time consuming to implement because they were developing their projects from scratch. Gustavo stated that "breaking the course into projects that assessed different CAD competencies was challenging". Grading project resubmissions was also time consuming, requiring up to 20 hours per week of ISA support. Corey explained in her reflection that this additional support is what made offering an MBG class possible for her and her co-instructors. Instructors should be prepared (and preferably have additional support) for the extensive time commitment necessary to both develop and implement an MBG, PBL engineering graphics course.

Another common theme was some difficulty in applying the MBG paradigm. Since Sam was the only instructor for Course 1, her main struggle was creating "new, more specific learning outcomes and detailed rubrics to use when evaluating each assignment". Additionally, she had to adjust her grading mindset since she was "more accustomed to a points-based grading system rather than grading based on mastery level". As a result, she chose to use MBG only on assignments and then use a traditional grading scheme for final grades by mapping each mastery level to certain point values. In contrast, while Corey, Gustavo, and Shardul applied MBG throughout Course 2, they struggled to implement a consistent standard of constituted mastery for each of the projects in the course. As Corey explained, they each "walked into the semester with very different conceptualizations of what 'mastery' by the students meant". This resulted in some grading issues, with Corey noting in her reflection that "students who were interfacing with multiple members of the instruction team" were sometimes frustrated because the instructors "did not have uniform expectations for each project part". While the instructors faced unique challenges due to the modality of each course offering, they all faced challenges when it came to grading that were not foreseen during course preparation. Their experiences point to the need for pedagogical training, support, and coordination to be provided to instructors to support an effective transition to MBG.

Another common experience for all instructors was that student evaluations revealed significant student support for the course structure and grading scheme. Students in both courses appreciated the flexibility afforded by having multiple submissions for each assignment. Sam found that "course evaluations revealed that students found the assessment methods to be fair in this class with students appreciating that they could submit each assignment multiple times to improve their scores". Additionally, Gustavo pointed out that one student said in their evaluations that "this course directly allowed me to feel proud of the production of the material" because they were able to repeatedly submit their work until they demonstrated mastery. Corey also noted that another student wrote in their evaluation that MBG, with its non-punitive approach, allowed them to make mistakes; "they wouldn't 'skip homework' if they didn't know how to do it, because 'the shame of doing it wrong' was absent". Additionally, the student said, "I find myself working on my project calmly and don't fear the feedback from the professor." This highlights a potential key feature of an MBG, PBL class: creating a space where students can learn without shame or fear.

The main differences in the themes highlighted above indicate that even in different engineering graphics class modalities, MBG and PBL overwhelmingly produce positive outcomes for the students and create spaces for the instructors to grow. Sam's main struggles included time spent grading resubmitted assignments and shifting her mindset away from a points-based grading system. At the end of her course, student evaluations showed that these struggles were worth the effort due to the overwhelmingly positive evaluations indicating that students appreciated that MBG afforded them resubmission opportunities for their assignments and the grading rubrics gave information on where they could improve. Corey, Gustavo, and Shardul's main struggles related to grading time and coordinating a class between three instructors since they each had different teaching experiences and ideas for what "mastery" meant in the context of project components. Unlike Sam, they had to collectively define "mastery", a process that takes time, discussion, and iteration. However, again, student evaluations revealed that these struggles were worth the effort because student evaluations revealed that students found the MBG, PBL structure to be beneficial to their learning. Despite these differences in experience, all four co-authors found developing and implementing a MBG, PBL engineering graphics class to have positively impacted their teaching style and created a space where students can learn with less fear of making mistakes.

Conclusion

This paper has demonstrated that, even with differences in instructor experience, both courses resulted in positive outcomes for the students and with each instructor feeling empowered to continue using both MBG and PBL. The themes present in the reflections demonstrate that MBG is achievable to implement while giving insight into potential challenges that an instructor implementing MBG may experience, regardless of their experience level with MBG. However, the analysis also points to the need for institutional support for instructors to both learn and implement alternative pedagogies, as there is both a pedagogical learning curve and additional instructional labor necessary to provide non-punitive student support. In sharing their experiences, the authors are adding to the literature on faculty perspectives on MBG and PBL and have shown a range of experiences that instructors may have when implementing these two pedagogies in an engineering graphics class.

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