Examining the Connection Between Student Mastery Learning Experiences and Academic Motivation

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Introduction

The National Academy of Engineers present the advancement of personalized learning as one of fourteen grand engineering challenges. Personalized learning has the potential to optimize the learning process by taking into account the unique learning fingerprint of each student. Every student will bring to a class different cultural outlooks, levels of motivation, interests in the material, and preferences for learning[1]. When students are properly supported, a greater degree of learning can occur both within the classroom and during independent practice[1,2]. One promising method of personalized learning is mastery learning, a theory described by Dr. Benjamin Bloom. When mastery learning has been applied to classes through intentional course design, the method has been shown to be successful in increasing the retention of course material without burdening the teacher or student with significant added time or effort[3].

The successful application of mastery learning theory relies on the implementation of a grading system built around the expectation of mastery[4]. For example, one instructor may determine that an entire problem's solution must be correct to determine mastery, while another instructor will accept a grade of 70%[4]. Mastery grading puts the emphasis on proficiency rather than categorizing a student using a traditional A through F grading system[2]. Increasing proficiency is a growing concern for engineering employers; in fact, employers seeking recent engineering graduates report that they place a high priority on proficiency during the hiring process, especially in general skill sets such as oral and written communication and ethical decision making[5]. It is not enough for students to learn the material presented. Students must become proficient in the skill sets offered by engineering programs[5].

Presented here is an analysis of an online gamified homework portal called Rezzly that utilizes mastery learning in six sections of a first year engineering design course. To gain insight into the effects of mastery learning, we collected data on the number of unpenalized attempts needed to complete homework problems (i.e., " quests") and academic motivation scores. This study seeks to answer two research questions: (1) Which quest content areas do students struggle with more than others on an online mastery learning homework system? and (2) What relationships exist between the number of attempts on an online mastery learning homework system and students' academic motivation? The results of this study provide information on what content first year engineers struggle with and the role that academic motivation plays in student perseverance.

Background

In the mid-1900s, the education community saw a rise in theories regarding personalized learning. The National Academy of Engineers [1] describes personalized learning as, "tailoring instructional methods to fit the needs and preferences of learners." A major theory that shaped personalized learning today is Bloom's Learning for Mastery (LFM). In this theory, Bloom discusses the importance of differentiating instruction and the impacts of LFM on academic performance as well as student engagement[2]. Engagement, however, is not intrinsic to a student but instead is a result of factors such as motivation, perception of the material, and the

learning environment[6]. Student motivation is studied here through the Jones' MUSIC Model of Academic Motivation[6]. This paper will discuss the insight gained by applying sections of the LFM assessment methodology to personalized online homework and comparing student performance with academic motivation.

Learning for Mastery

The LFM approach, also referred to as simply "mastery learning", was proposed by Bloom to address the gap in achievement that occurs when course design is built upon the expectation that student academic performance will adhere to a normal distribution[2]. According to conventional education standards, only 10% of students will achieve the level of mastery determined by the instructor to achieve an 'A' grade[7]. The goal of a grading system is to categorize students on a spectrum ranging from failing to demonstrate understanding (F grades) to achieving a full understanding (A grades). According to Bloom, shifting the focus of instruction away from the expected distribution and towards personalized learning can lead to as much as 90% of a class achieving mastery[2].

Following Bloom's advice for utilizing personalized learning in a classroom means teaching towards five main components: (1) student aptitude for particular kinds of learning, (2) quality of instruction, (3) student ability to understand instruction, (4) student perseverance, and (5) adequate time allowed for learning. The model suggests that adding these components to supplemental course materials such as homework is a highly accessible way to implement the LFM strategy[2,8]. This background will describe previous studies on mastery homework and the findings as they relate to student perseverance and performance.

One case of mastery learning being applied to engineering homework assignments is presented by Moore and Ranalli [9]. A large university was analyzed in the context of core engineering science courses such as thermodynamics, dynamics, and strength of materials. This study implemented a grading scheme (Mastered, Not Mastered, and Not Attempted) that reflected the goals of a mastery based assessment. Personalized feedback was given to students within a week, and those students who did not reach mastery could resubmit on a weekly basis with no reduction in their score. In a qualitative analysis of the mastery system presented, students reported that the repetition of problems became time consuming while the instructors experienced the opposite- grading with the mastery system took less time than evaluating with a partial credit system. Subsequent interviews done by Moore analyzed the perspective of students both during and after the completion of the same course[9]. Interviews done with current students revealed the same time concerns as before. However, the same students reported a year later that the mastery homework was a fair and representative evaluation of their abilities and led to more collaboration with peers. Over half of the class later reported that the grading system motivated them to pursue the correct answer more than a traditional grading system. Although students were faced with concerns over the time consumed by a long series of attempts, the academic benefits may outweigh this stress.

In another instance, mastery homework was applied in an introductory physics class by Gutmann *et al* [10] where students were allowed to self-pace within the week that homework was assigned and were given a maximum of four attempts to complete a problem. A comparison of student attitudes and performance at week three and week seven revealed that, as time passed,

students adopted more productive behaviors by utilizing the online video resources provided and needed fewer attempts overall to complete a homework problem. However, the upper limit of four attempts resulted in fewer students completing homework overall at week seven. Despite this, Gutmann et al claimed an overall positive experience, stating "students felt a more compelling sense of agency and performed more as mastery theory prescribes, demonstrated by students' higher rate of mastering levels and using correctives (in our case, video solutions). [10, p. 7]."

Jones MUSIC Model of Academic Motivation

Education stakeholders are greatly interested in academic motivation. A motivated student is more likely to be engaged and persevere through learning difficult content[13]. The factors that affect motivation also have a significant effect on the success of mastery learning[2]. Furthermore, motivation is a result of many different psychological considerations. For this reason, we have chosen to use the Brett Jones MUSIC Model of Academic Motivation as a tool for analysis in this study. This model is a theoretical model that ultimately suggests intentionally designing courses to better motivate students[14]. The MUSIC model draws on a social-theoretical framework to describe five central components to academic motivation: empowerment, usefulness, success, interest, and caring[13]. It is suggested that instructors purposefully design courses to support these five components. The components of the Jones' MUSIC model and example interventions are summarized in Table 1.

The motivational scores in the MUSIC model are determined by the MUSIC Model of Academic Motivation Inventory, a 26-item Likert Scale survey. An analysis of the MUSIC model was performed by Jones and Skaggs[15] which showed convergent validity when compared to smaller existing instruments that correspond to the five MUSIC model components. This model has proven to be a useful analytical tool for engineering educators. The Jones MUSIC model can serve as both an instrument for analysis and a useful lens for viewing student engagement[14,15]. It has been used for a variety of engineering education studies, including assessing the effects of instructional methods on motivation[14], and also determining student motivation to engage in an online environment that leverages gamification[16].

Table 1: The Jones MUSIC Model of Academic Motivation Summarized

Component	Definition	Example Instructional Strategies[13]
Empowerment	The choice to feel as though they have the power to have control over their learning process	-Design assignments to give students choice -Structure larger assignments such that due dates are further apart to allow students to self-pace
Usefulness	The extent to which a student views a course as being valuable to their future	-Explicitly identify how the course content is relevant -Provide opportunities to apply course material
Success	The perceived ability to be successful when faced with academic challenges	-Set clear and detailed expectations -Give challenges that are suitable for the academic level of the students
Interest	A natural, sustained curiosity for a topic (individual interest) combined with the contextual interest in a topic (situational interest)	-Connect course topics to background knowledge -Use techniques for engagement (active learning, enthusiastic presentations, humor)
Caring	A professor's expression of support surrounding classwork (academic caring) and the wellbeing of the student (personal caring)	-Reach out to underperforming students often -Respond to student emails promptly

Research Questions

This study is guided by the following two research questions:

Research Question 1: Which content areas do students struggle with more than others on an online mastery learning homework system?

Research Question 2: What relationships exist between the number of attempts on an online mastery learning homework system and students' academic motivation?

Methods

Study Design

This study took place within a second semester first year engineering design course. The course is required of all engineering majors and covers topics such as statistics, engineering economics, ethics, intellectual property, and MATLAB. Content information for the course is provided through instructor delivery as well as an online text resource. The course grade involves multiple components such as project activity completion (reports, interim deliverables, etc.), a midterm, a final exam, and 15% of the course grade involves the completion of assignments within an online gamified homework portal, Rezzly[17].

Six sections of this first year course were analyzed for this research study: three honors sections and three standard sections. In total, 154 students across these sections provided online

data on homework completion. Of these students, 88 students also completed the MUSIC model survey[18] to provide data on student academic motivation.

Gamified Homework Platform

Rezzly is an online gamified homework platform that provides an opportunity for students to personalize their homework experience within the course. A student using the Rezzly homework portal will have the opportunity to use an anonymous username, known as a gamertag, as well as upload a personalized avatar. Under the guise of their avatar, students will complete "quests", or homework questions, for experience points (XP) and see themselves climb the class leaderboard. An example of a quest on Rezzly is shown in Figure 1. On the Rezzly landing page, students can choose quests based on category, quest description, average rating, average time to completion, and XP. Once students complete a quest, it is submitted for review by graders on the platform. Students may find that either a grader has determined the content of the quest has been mastered, leading to its approval or that the quest has been returned, demonstrating that they have not yet mastered the content. Whether quests are returned or approved, students receive personalized feedback on their completed work.

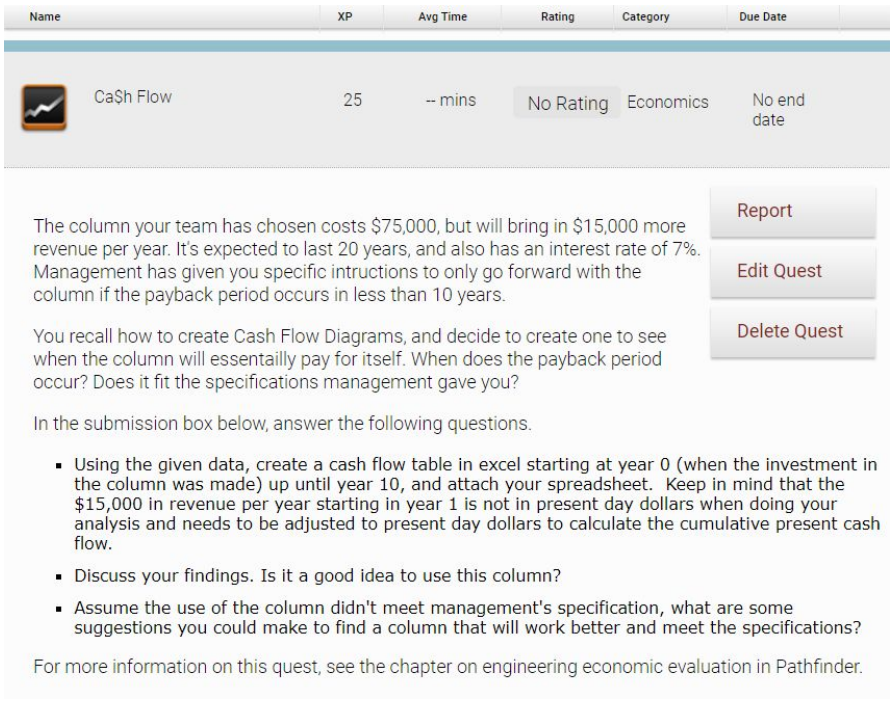

Figure 1: Screenshot of a quest within the Rezzly platform[17].

Quests within Rezzly are scaffolded based on content area and level of difficulty. Each quest belongs to a category that reflects the goals of the first year engineering program. The categories are summarized in Table 2.

Table 2: Quest Categories in the Homework Platform Summarized

Category	Topic Examples	Number of quests available
Communication	Public speaking, structuring reports, writing emails	6
Economics	Engineering economics, personal economics	10
Engineering Impact	Sustainable development, safety design	6
Engineering Tools	MATLAB programming, programming basics	9
Ethics	Personal ethics, normative ethics, situational ethics	8
Intellectual Property	Patents	8
Problem Solving	General design, debugging	5
Product Development	Affinity diagrams, activity networks	8
Statistics	Data representation, error bars	10
Teamwork	Team member contracts, team projects	4
Professional Development	Project structuring, entrepreneurial mindset	5

Mastery Learning Elements

The design of Rezzly aligns with the five elements of mastery grading theory as summarized again here: (1) student aptitude for particular kinds of learning, (2) quality of instruction, (3) student ability to understand instruction, (4) student perseverance, and (5) adequate time allowed for learning[2]. Students are provided multiple types of instruction for each quest. The instructions in a quest regularly contain information and resources that can aid in finding a solution. The homework quests also align with the course which means the students have access to an instructor as a resource as well as an online text resource.

The aspects of the gamified homework portal that serve to support students of different aptitudes also assist with the quality of instruction. The resources provided include multiple forms such as informational text, video instruction, diagrams, infographics, and news articles. However, the major element of Rezzly that supports quality of instruction is prompt feedback. Students receive personalized feedback from upper-level student graders within 48 hours of their submission. This allows each student to be supported individually through more difficult solutions. A student's ability to understand instruction will inevitably vary. In order to combat this, the multiple resources provided to the students are "…a means of helping individual students at selected points in the learning process - and that a particular student may use

whatever variety of materials are found to be useful as he encounters difficulties in the learning." [2, page 6].

Perseverance also naturally varies from student to student depending on individual and contextual factors. Rezzly creates opportunities for students to persevere by allowing unlimited attempts on each quest. Quests on the homework platform also have no deadlines. Some quests are available immediately after an orientation to the platform while others do require prerequisites to be completed ensuring that the students have the necessary foundational knowledge prior to attempting a quest. The combination of unlimited attempts and a lack of deadlines is intended to create an environment in which students have choice in self-pacing as well as the freedom to fail.

Data Collection

Upon conclusion of the class, the following information was tabulated from the records within the online gamified homework platform for every completed quest within the studied sections: username/gamertag, quest name, quest category, and the number of unique attempts needed to complete the quest. All of these students were provided the opportunity to complete the MUSIC model questionnaire[17] at the end of the semester although only a sub-section of the students opted to participate. Proper human subjects' approval was obtained prior to data collection.

Data Analysis

The data collected regarding the number of attempts was analyzed in the context of both research questions. For research question one, the number of attempts needed for students to complete a quest was analyzed across all ten categories. Since the results were not continuous, a nonparametric one-way ANOVA test was completed using SPSS in order to compare the categories. The effect size for this study was calculated using Cohen's D. For the second research question, the average number of attempts for each student was compared to each of the five components of the MUSIC model by calculating the Pearson correlation coefficients using SPSS[19]. Data was then compiled into RADAR plots in order to evaluate the relationship between academic motivation and the number of attempts needed to complete a quest. Data was categorized as being from three categories: all students, the top 20 performing students, and the bottom 20 performing students as measured by the average number of attempts. The difference in populations was analyzed using an independent samples t-test which is reported alongside a Cohen's D effect size.

Results and Discussion

What content areas do students struggle with most?

Analyzing the number of attempts needed by category for undergraduate engineering students was done in order to serve two purposes: the results allow an insight into what content areas may be a source of academic struggle for engineering students, and the analysis will help to adjust the design of the homework platform to provide better resources. The summary of this analysis is shown in Table 3.

Table 3: Results Showing the Average Number of Attempts for Each Category

Category	Average Attempts	Standard Deviation
Communication	1.82	0.68
Ethics	1.76	0.88
Statistics	1.67	0.81
Professional Development	1.41	0.61
Economics	1.37	0.72
Engineering Impact	1.23	0.44
Intellectual Property	1.2	0.49
Engineering Tools	1.13	0.39
Teamwork	1.11	0.32
Problem Solving	1.08	0.28
Product Development	1.07	0.27

It was found that, for the 154 engineering students analyzed here, the quests in the communication category routinely needed the most number of attempts to get approved (1.82). This result was compared statistically to the category that required the least number of attempts on average (1.09), product development. The one-way ANOVA test yielded a p-value of 0.097, indicating that the results were not highly significant and therefore further individual tests between the categories would produce similar results. However, a large Cohen's D of 1.46 implies that there is a statistical difference between the data collected from both categories.

Results indicating that first year engineering students are struggling most with communication assignments are in alignment with reports that engineering graduates show a distinct lack of communication skills[20]. Many different factors are present when first year undergraduates are approaching a communication assignment: previous schooling in communication, language barriers, perception of the content, and even the feedback they receive after submitting an attempt. The difficulty of the content itself may play a role, however it has been reported that first-year engineers perceive common engineering courses that focus on communication aspects to be easier than strictly engineering design and problem solving courses[20]. It has also been shown that engineering faculty are often ill-equipped to provide feedback on communication assignments. In this study, communication feedback is given by upper-level engineering undergraduates. This may cause additional struggle with communication quests. Another factor impacting the performance on communication quests, as well as other interdisciplinary content (ethics, statistics) could include the perception of the usefulness of content. The results of research question two discuss the relationship between a student's overall

motivational scores, specifically the usefulness motivation score, and their performance on Rezzly.

What relationships exist between the number of attempts and academic motivation?

Mastery learning theory states that perseverance is an integral part of a student's academic success[2]. The Jones MUSIC model of academic motivation also regards perseverance as a trait associated with a highly motivated student. Persistence through a task, represented here as submitting an assignment multiple times until it is finally accepted, is dependent partially on the extent to which a student believes success is possible and whether an instructor cares about the success of that student[13]. The relationship between the number of attempts (perseverance) and motivation is shown in Figure 2 through Pearson correlation coefficients.

No strong correlation coefficients were found, although a slight negative correlation is present in the relationships between the number of attempts and the empowerment, usefulness, and interest scores. The negative correlation implies that students who need fewer attempts to find a correct solution for a quest have higher motivation scores. Although both mastery learning and Jones' MUSIC model of academic motivation predict that the caring motivational score is related to a student's persistence through a task, there was no correlation found between the caring score and the number of attempts needed to complete a quest. However, the students that needed a higher number of attempts did have a caring score that was about equal to both the caring score of the average student and to that of students that needed a lower number of attempts.

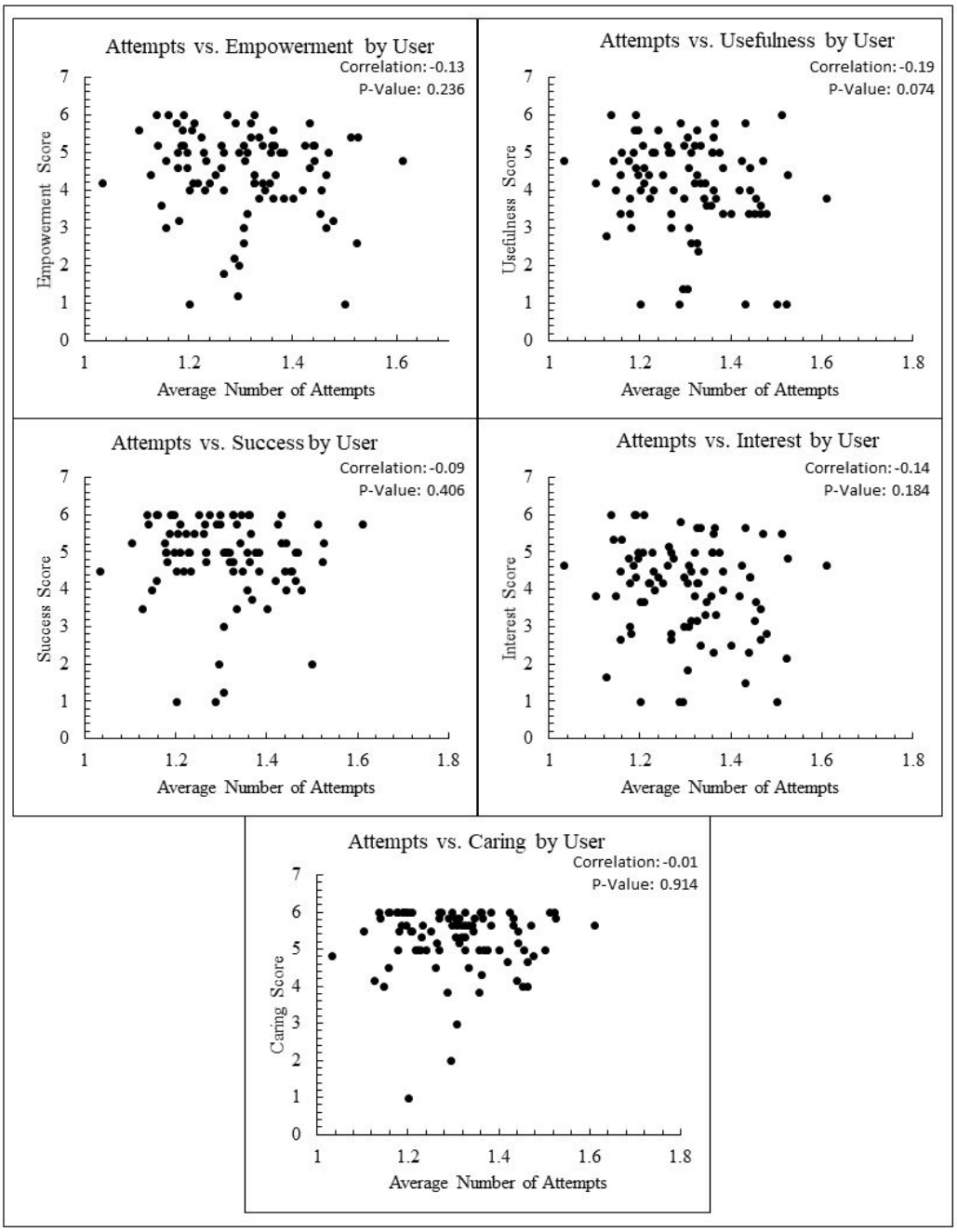

Figure 2. Motivational scores plotted as a function of the average overall number of attempts needed by students.

Although there is little evidence that the individual motivational scores correlate with the number of attempts needed, there is an overall trend present when considering the motivational scores in full. In Figure 3, the results are separated into two categories: the average motivational scores of the twenty students with the lowest number of attempts needed and the average motivational scores of the twenty students with the highest number of attempts needed. The students that require less attempts to complete a quest have consistently higher than average scores across all five categories. For example, as shown in Table 4, students with the lowest

number of attempts had an average empowerment score of 4.85 while the average empowerment score across the entire sample size was 4.47. It was found that the caring motivational scores of the students who need the highest number of attempts is approximately equal to that of the average caring score. The biggest difference in motivational scores between the two isolated populations is in the usefulness and interest categories, which is consistent with the results of the correlation coefficients reported in Figure 2.

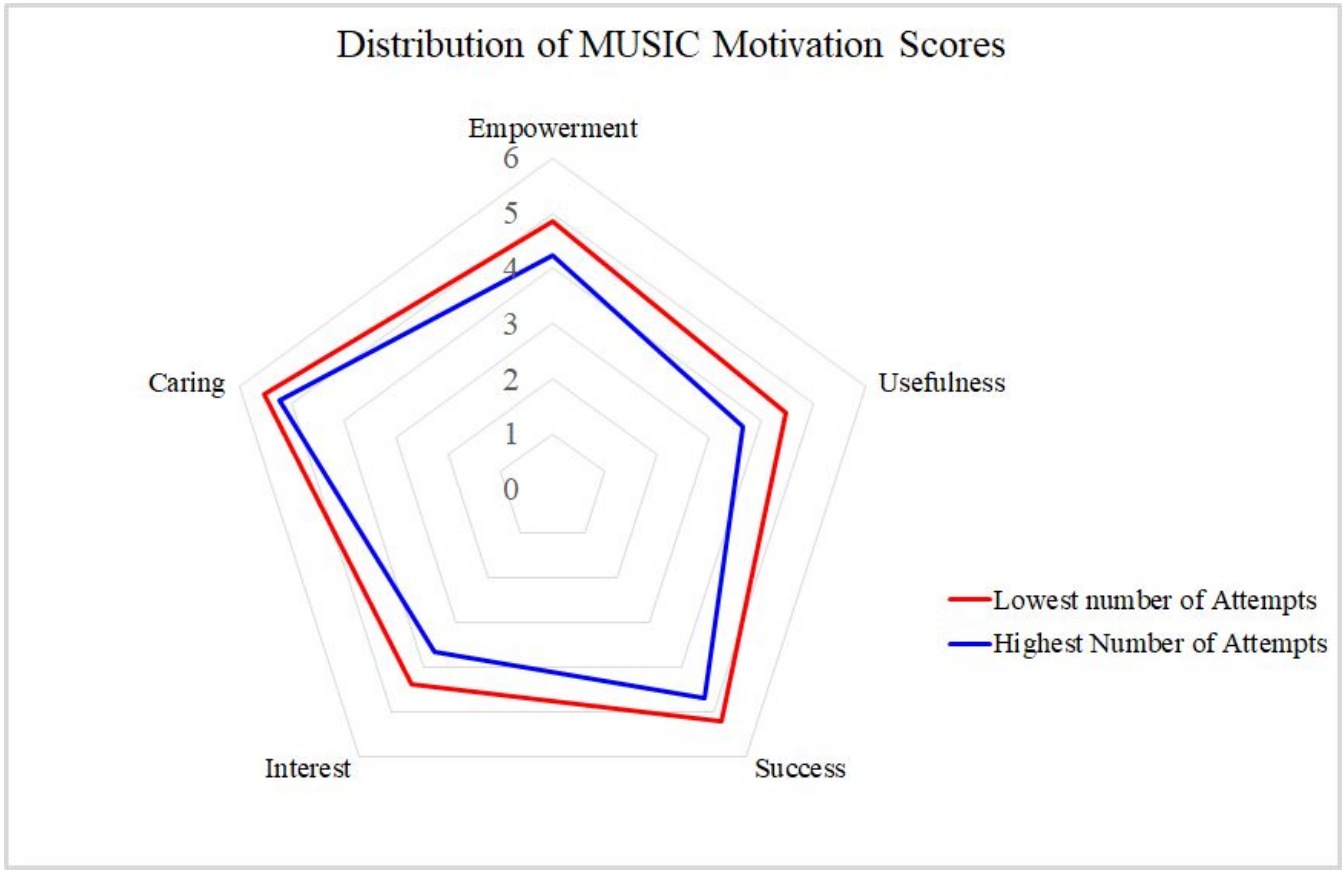

Figure 3: MUSIC Scores distributed in a RADAR plot.

The difference in usefulness motivational scores between the low and high number of attempts populations was found to be statistically significant ($p<0.05$). As shown in Table 4, the students with the lowest number of attempts had an average usefulness score of 4.48 while the students with the highest number of attempts had an average usefulness score of 3.65. Previous studies have shown that engineering students are motivated by usefulness in situations where their work may be useful to others or society in general[14], the usefulness of material to their career goals[13,14] and usefulness to their future careers[13,14,22]. Studies done on motivation suggest that a direct explanation of the usefulness, or utility value, of an assignment will improve the performance of a student who is motivated by usefulness[22]. In this case, any explicit detail provided on the usefulness was done so by the instructors and is likely to vary.

Table 4: Statistical Comparison of the Top Performing Students and Low Performing Students

	All Students		Lowest Number of Attempts		Highest Number of Attempts		Statistical Comparison Between Lowest / Highest	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	p-Value	Effect Size
Average Attempts	1.30	0.11	1.16	0.04	1.46	0.05	0.00*	6.73
Empowerment Score	4.47	1.15	4.85	0.88	4.23	1.15	0.07	0.61
Usefulness Score	4.12	1.22	4.48	0.90	3.65	1.34	0.03*	0.73
Success Score	4.88	1.10	5.21	0.76	4.69	0.90	0.06	0.63
Interest Score	4.02	1.26	4.36	1.15	3.63	1.31	0.08	0.58
Caring Score	5.27	0.87	5.53	0.65	5.22	0.65	0.14	0.49

* Statistical significance ($p<0.05$)

Although we cannot make any assumptions as to the reason the usefulness scores varied to this extent, it is clear that the students that are less motivated by usefulness required significantly more attempts on average. Students that are highly motivated by usefulness are spending less time and less repeated effort on quests and are more likely to complete a quest on the first attempt. Conversely, students who are experiencing difficulties and require many attempts may be discouraged and have a lower usefulness motivation score as a result. Overall, the results further corroborate efforts to intentionally design instruction to both identify the usefulness of the content or assignment, and also to provide opportunities for application of material[13,14,22].

Limitations

The data collected for this study was from six sections of the first-year undergraduate engineering design course. Of the 154 students that were participating in Rezzly, only 88 students consented to the MUSIC model of academic motivation questionnaire. Due to the small sample size, the generalizability of the results is limited. In addition, prior use of Rezzly in the classroom demonstrated the need for deadlines on the platform. Although the quests themselves are without deadlines, the course curriculum specified semi-monthly XP benchmarks that students were required to meet. This presents a possible limitation of the effectiveness of the intervention due to the importance placed on self-pacing in mastery learning theory.

Conclusion

The first-year undergraduate engineering design course studied here is implemented with the goal of creating well-rounded engineers. In order to help achieve this goal, a gamified online homework portal is used to provide a personalized learning experience to students. The homework portal applies mastery learning theory by allowing students to submit unlimited attempts to homework problems, receiving quick and personalized feedback, and allowing the students to self-pace when progressing through the system.

This study asked what content areas engineering students struggle with in the online homework portal as measured by the number of attempts needed to successfully complete a quest. It was found that the communications category is, on average, an area of weakness for engineering students. This result, in comparison to other content categories, is statistically insignificant although the result is supported by a large effect size. These results may be due to insufficient grader feedback, or perceived usefulness of the material. In addition to studying the attempts necessary by content area, the behavior on this platform was analyzed in the context of academic motivation. When analyzing the distribution of the five academic motivation elements, it was found that higher performing students had overall higher motivation scores than lower performing students.

The biggest difference in motivational scores between the two populations was seen in the usefulness score. The highest performing students on the platform were significantly more motivated by usefulness than the lowest performing students and needed 21% less attempts on average. This study included no intervention to address the usefulness of the system, the content, or the quests itself. Therefore the relationship between the performance of a student and the usefulness motivation score is directly resulting from the students' own perception of the usefulness of the quest as well as their motivation. The results of this study suggest that, in future uses of mastery learning in homework, an explicit connection between the content and usefulness to an engineering career may be necessary for students to perform to their highest potential. Since the area of struggle for students is most commonly the interdisciplinary categories, this study overall suggests that these interventions would be most effective in content areas such as communication, ethics, and statistics.

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