Supporting Mastery Learning Through a Multiple-Submission Policy for Assignments in a Purely Online Programming Class

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Abstract
The Learning Edge Momentum (LEM) theory suggests that once students fall behind, it gets more difficult to catch up with the course material. It then becomes increasingly more difficult to connect new, higher-level concepts to those solid edges of knowledge with mastery of basic concepts. Learning for Mastery (LFM) acknowledges that students learn at different paces by allowing students unable to master tests the first time to catch up eventually. This paper describes how an online introductory Python programming course offered to business students followed a multiple-submission policy for assignments to support LFM. The multiple submission policy contributed to the students' mastery by encouraging individual practice and experimentation while also increasing the students' comfort level and confidence. The research attempts to find relationships between taking advantage of the multiple-submit policy and results of summative assessments. Qualitative data on students' self-reported progress per week is cross-referenced with quantitative data from the results of a regression analysis performed on LMS logs related to students' engagement with course material. Performance on summative assessments is used as the regression's dependent variable, and engagement with formative assessments in terms of the number of attempts and performance per attempt is used as the explanatory variable.

Keywords: Learning Edge Momentum, Mastery Learning, Online Learning, COVID-19, Python Programming, Multiple Submissions, Transactional Distance, Self-Efficacy, Scaffolding

Introduction

Learning involving subjects such as basic computer programming, unlike other subjects, there seems to be a bimodal distribution or double hump of grades (Dehnadi and Bornat, 2006; as cited by Robins, 2010). The Learning Edge Momentum (LEM) theory, as proposed by Robins (2010), suggests that once students fall behind, it gets more difficult to catch up with the course material. It then becomes increasingly more difficult to connect new, higher-level concepts to those solid edges of knowledge with mastery of basic concepts. Learning for Mastery (LFM) acknowledges that students learn at different paces by allowing students unable to master tests the first time to catch up eventually.

Context

The authors of this paper are relatively new to teaching in tertiary education, with the students assigned mostly business management majors of the John Gokongwei School of Management of the Ateneo de Manila University in the Philippines.

In the specific case involving this study, the class covered an Introduction to Python Programming. Neither computer science nor programming may not necessarily be top of mind for the students involved. Informal survey responses at the start of the class show that while many students did have programming instruction exposure in senior high school, most of them already forgot what they took up.

In previous rounds of this class, whether online or offline, student performance in programming classes had been bimodal rather than a single-mode curve. Anecdotally, fellow instructors who have been teaching much longer than we have had also been observing the same thing, with one of them exclaiming that "in programming, it's either you know it, or you don't." This is consistent with the assertion of Dehnadi and Bornat (2006), that experienced programming teachers believe that there are at least two populations in initial programming courses. They give the following quote (Robins, 2010):

“All teachers of programming find that their results display a ‘double hump’. It is as if there are two populations: those who can, and those who cannot, each with its own independent bell curve.”

Motive

The current pandemic has forced the University to shift to online education. The shift included a mandate to use Canvas as the Learning Management System (or LMS) for the whole university. With the LMS, the researchers saw an opportunity to take advantage of data collection, asynchronous modes of course delivery, and a more accessible facility to manage the submission of assignments and tests. The bias for course design, as pushed by the University, was asynchronous because of the problems involving Internet access.

With the available technology tools, there was an opportunity to determine if the attainment of mastery can be deliberately supported through course policy and design.

Learning Edge Momentum

Previous work explains some of the anecdotal findings heard over time relating to the bimodal nature of programming class assessments and outcomes. Robins (2010) proposed the learning edge momentum theory to explain why there seems to be a bimodal distribution or double hump of grades in subjects like computer science and introductory programming courses. It's hypothesized that it gets more challenging to catch up with the course material once students fall behind. In reverse, it is somewhat easier to acquire additional related concepts from the domain for any successful learning at the start, where the fundamentals are established.

If the student already has the fundamentals mastered early on, then knowledge acquisition at the address will be much easier, hence the learning edge momentum. On the other hand, this structural bias is brought about by certain learning styles, and the inherent nature of the content, such as computer programming, will drive students to opposite ends of the performance spectrum.

Mastery Learning

Mastery learning is founded on the principle that all students learn differently but are all capable of learning well when given the appropriate instructional conditions. In addition, mastery depends on how well the teachers diagnose and correct the learning difficulties of the students (Amurao & Ilagan, 2021). "Teachers can teach so that all students *do* learn well" (Block & Burns, 1976). According to Bloom & Carroll (1971), mastery learning results in both cognitive and affective outcomes. Cognitive outcomes manifest in the students performing well on the subject as quantified by grades, while affective outcomes emerge through impact on the students' outlook of themselves and the world. They are encouraged to believe that they are equipped to cope with challenges, which makes them more resilient and empowered to achieve mastery. This applies not only to classroom concepts but lifelong learning as a whole (Bloom, 1976).

Learning for Mastery Strategy

The Learning for Mastery (LFM) strategy is one of the approaches towards mastery learning. It is based on John B. Carroll's (1963, 1965) model where he proposes that if students exert and are allowed the time they need to learn a concept to a certain level, they probably could. The degree to which students are able to learn is related to two main factors, which are time spent learning and time needed to learn the concept. Carroll further breaks down these two factors further:

1. Time spent learning is determined by:

a. The student's perseverance, as defined by the amount of time the student is willing to give to learning the concept

b. Their opportunity to learn, which is defined by the actual classroom time allotted for learning the concept

2. The time needed to learn is determined by:

a. The student's aptitude for the subject, which refers to the time they need to learn the concept under ideal instructional conditions

b. The quality of teaching instruction they receive and their ability to understand the instruction, which refers to the additional time they would need to learn the concept under less than ideal instructional conditions

Block & Burns (1976) relate all these factors in the following statement: "the degree of school learning of a given subject depended on the student's perseverance or his opportunity to learn, relative to his aptitude for the subject, the quality of his instruction, and his ability to understand this instruction."

From Carroll's model, Bloom designed the LFM strategy around addressing the teacher-dependent variables, which are the opportunity to learn and the quality of teaching instruction. Bloom's approach has 4 different components (Block & Burns, 1976):

1. *Defining mastery* by identifying the learning outcomes, preparing a final summative assessment to measure mastery of the learning outcomes, breaking down the course into smaller units, and determining what learning outcome each unit addresses.
2. *Planning for mastery* by outlining how the teacher will present the materials to the students, developing formative assessments for the end of each unit to gauge mastery level, and developing correctives for each item of the formative assessment. The correctives may consist of group sessions, individual tutoring, or other learning resources (e.g. textbooks).
3. *Teaching for mastery* by providing initial instructions, administering diagnostic-progress testing, certifying students with mastery, and correcting those without mastery for all units.
4. *Grading for mastery* by administering the final summative assessment and quantifying the students' mastery using grades relative to the learning outcomes set instead of the other students' grades.

Guskey (2005) further elaborates on the mechanism of planning and teaching for mastery in Figure 1. The end-of-unit assessments are formative because they provide the teachers' insight into the students' learning progress, which the teachers can develop action points from on a class and individual level. Once formative assessments are administered, it is crucial for teachers to diagnose the students' individual learning difficulties and provide corrective or enrichment activities as needed. If the correctives are given within the appropriate amount of time, they can help prevent minor learning difficulties which can later accumulate into major problems and hold the student back from achieving mastery. After the corrective procedure has been given, Bloom recommends that students take a second formative assessment with the same difficulty level and address the same learning outcomes. This gauges whether the corrective was effective in addressing the student's learning difficulty that was being targeted. If the student has achieved mastery for that unit, then they can proceed to the next one. For students who scored well on the first formative assessment and did not require correctives, they may be given enrichment activities instead to further their learning.

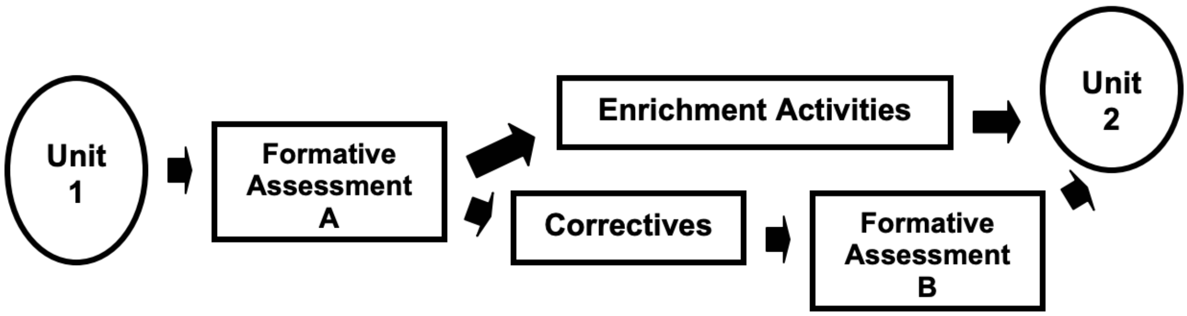

Figure 1: The Mastery Learning Instructional Process (Guskey, 2005)

Creative confidence is the natural ability to ideate and try new ideas. According to Kelley & Kelley (2012), reclaiming creative confidence means overcoming fears of the unknown, judgment, first steps, and lack of control. Fear of judgment relates to the concept of psychological safety, which is defined as “being able to show and employ one's self without fear of negative consequences of self-image, status or career” (Kahn, 1990). The presence of fear of judgment, or the lack of psychological safety, manifests when students censor themselves and share only ideas they perceive to be safe to avoid being judged by peers or instructors. A common quantitative measure of judgment in the academic setting is grades. If having a higher grade is emphasized over actual learning outcomes, students’ fear of judgment worsens. As an effect, students may become set on the idea of just providing the right answer instead of learning through the process, avoiding difficult tasks, or avoiding asking questions and when they fail to overcome their challenges, they blame themselves and damage their self-esteem. The use of formative assessments helps address this problem because it helps teachers identify what the learning difficulty is and correct them (Black & William, 2010). In the case of there being more than one chance of answering the formative assessment, psychological safety is encouraged. Without the pressure of the first grade being the final one, students may take more risks when answering assessments (i.e. reduce self-censoring of ideas) and feel that they are able to achieve as they are guided in overcoming the students’ individual learning difficulties.

Additional Theoretical Frameworks

Transactional Distance refers to physical (especially in distance learning), pedagogical and psychological gaps, particularly between instructor and student and among students (Moore & Kearsley, 2011, as cited by Ilagan, 2020).

Self Efficacy Self-efficacy refers to the belief of a learner to attain specific performance levels through behaviors needed (Bandura, 1977).

Given the online setting, guided by the theories of transactional distance and self-efficacy, there was the need to provide a healthy mix of structure dialogue and self-autonomy in the course design.

Research Questions

The overall direction of this study involves determining the relationship between deliberate course design to allow and encourage mastery and effects on learning outcomes.

RQ1) What is the general student attitude and behavior towards mastery if given the chance?
To arrive at the answer for this, we may have to ask the following: What is the average number of attempts before reaching mastery? For those who did not attain mastery, how many times did they submit/resubmit on average? What is the general summative score/grade distribution of those who choose not to achieve mastery?
those who achieve mastery? What are the earliest submission dates of those who achieved mastery and those who haven't?
RQ2) What is the relationship between mastery of learning attained during formative assessment and summative assessment outcomes? Determining the relationship between the number of submission attempts and summative assessment grading outcomes may help answer the question.
RQ3) What aspects of mastery can we actually target with classroom policies?

Methodology and Course Design

The study was conducted in the context of an introductory course to computer applications programming for undergraduate students called ITMGT 25.03: Information Technology Application Programming. The students who took the course were second-year Management Engineering students. Students of this profile are expected to be between the ages of 18 and 20, though the study was unable to obtain precise data to verify this and catch anomalies.

With clearance from the University's Research Ethics office, we sought student access logs and grades stored in the back-end Canvas server. Most of the quantitative insights aimed at addressing the research questions in this study came from the analysis of the logs.

Classroom Setup

In total, there were 81 students who took the course. The course timeline covered six calendar weeks from June 30, 2021, to August 8, 2021. There were six content modules in the class. The aim was for students to consume content at the rate of one module per week. The mode of course content delivery was fully online through text and videos hosted on the Canvas Learning Management System (LMS). Course assignments and assessments were written as Python Jupyter notebooks and were hosted on GitHub. The course did not hold any synchronous classes, although the instructors held consultation sessions on request. Summative assessments were conducted in time boxes, which means that students could only answer them during a designated period of time.

The main mechanism highlighted in this study is that the course's formative assessments could be submitted repeatedly by students until they got a grade with which they were satisfied. Due to the nature of the formative assessments (programming assignments on Jupyter notebooks), instructors could check submissions multiple times a day using automated grading scripts, which could also provide feedback to students quickly. It should be noted that the course's formative assessments did not use the gating approach. The formative assessments had no deadlines, unlimited submission attempts, and no forced order. This approach was chosen to promote psychological safety.

Findings

This study examines a subset of data available from the whole course from July 2 to July 14, 2021. July 2 was close to the start of the class timeline, and it was also the date that the course received its first formative assessment submission attempt. July 14 was one day after the first summative assessment, which was a departmental test. In this time window, there were two formative assessments: one of these formative assessments was introductory, and another was comprehensive (with respect to the fundamentals of programming). This subset was chosen to minimize the chance of interference of other factors with the behavior of students, as course mechanics were materially altered later in the class timeline to adjust for unforeseen events.

In this time window, of the 81 students who took the course, 61 eventually scored full marks on both formative assessments, and 20 did not. This distinction will be used as a proxy for whether a student "mastered" the subject matter. Using this indicator for mastery, it can be interpreted that the 61 students achieved mastery and that 20 did not achieve mastery.

There are notable differences between the engagement metrics of these two groups. On average, students who achieved mastery submitted both earlier and more often than students who did not achieve mastery. The following graph presents the cumulative average number of formative assessment submissions per group at any point in time. The students who achieved mastery submitted earlier and more often at every point in time over this two-week period than students who did not achieve mastery.

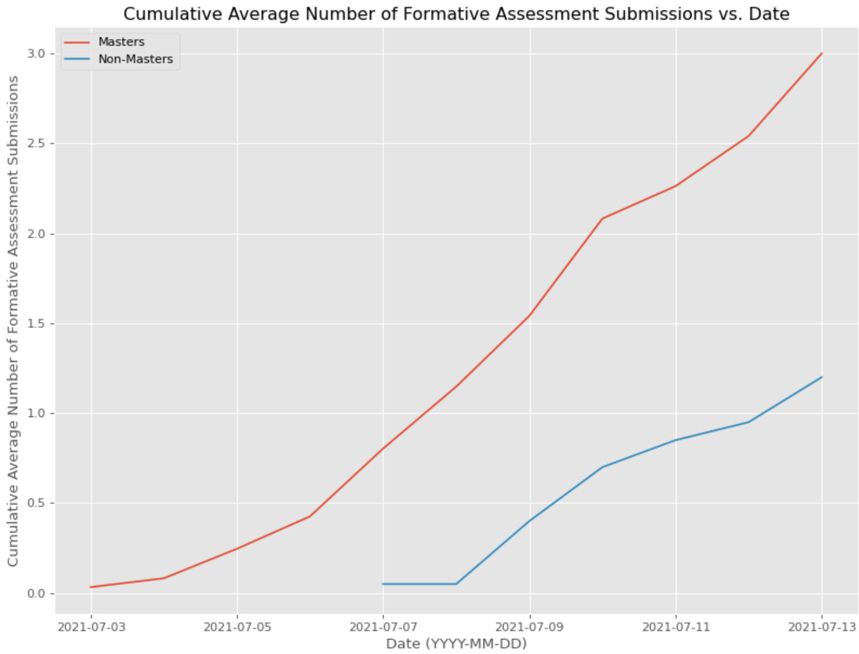

Figure 2: Cumulative average number of formative assessment submissions over the duration of the course

There are also notable differences between the performance metrics of these two groups on the summative assessment. In short, students who achieved mastery appear to have performed both better and more consistently than students who did not achieve mastery. To illustrate the quality of performance, out of 200 points, students who achieved mastery scored an average of 175 points, and students who did not achieve mastery scored an average of 152. Adjusted to the university's grading scale, the students who achieved mastery scored an average score equivalent to a B+, and students who did not achieve mastery scored an average score equivalent to a C+. To illustrate the consistency of performance, the distribution of the scores of the students who achieved mastery has a standard deviation of 25, whereas the distribution of the scores of the students who did not achieve mastery has a standard deviation of 42. The following graphs illustrate the visual distribution of the scores of both student groups. It is apparent that the graph of the scores of students who achieved mastery is left-skewed and concentrated near its mode, whereas the graph of the scores of students who did not achieve mastery is more spread out.

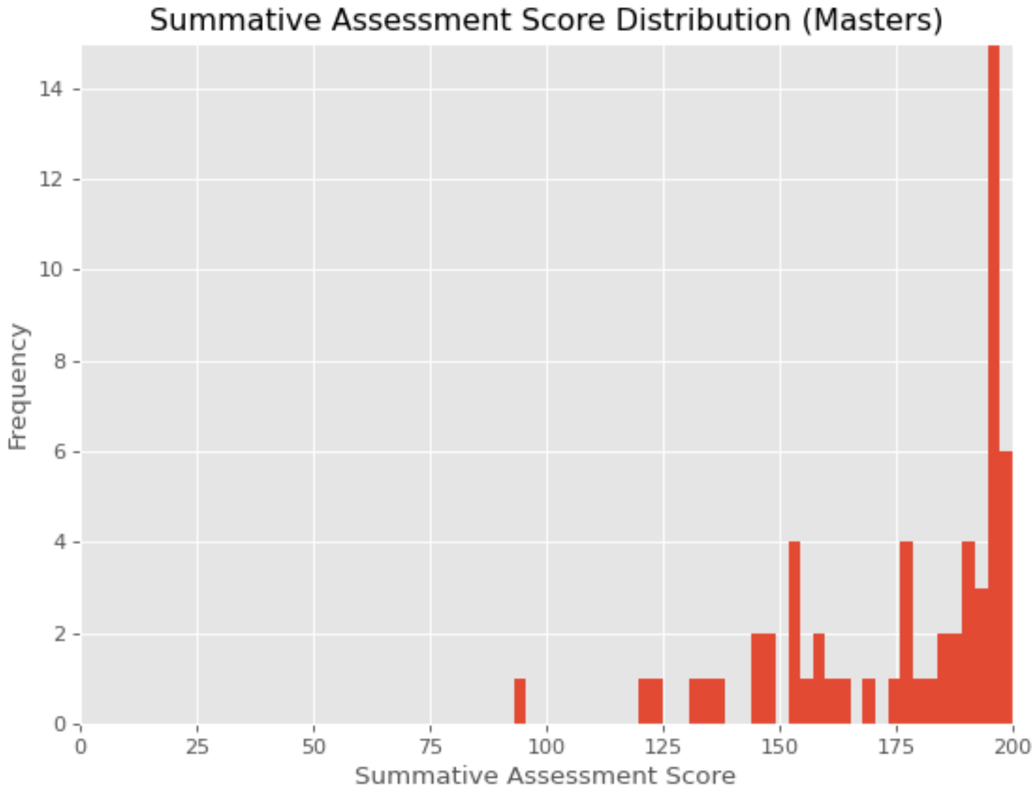

Figure 3: Summative assessment score distribution of those interpreted to have achieved mastery

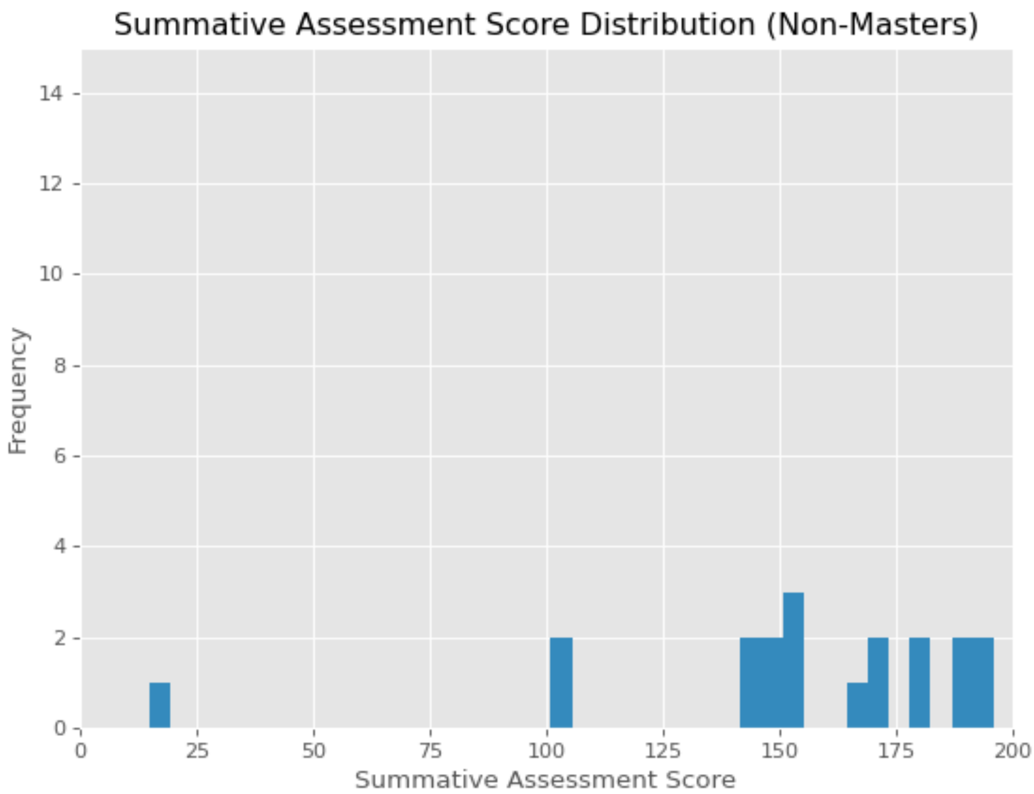

Figure 4: Summative assessment score distribution of those interpreted to not have achieved mastery

This study also explored two other potential explanatory variables for the difference in performance: first, the lateness of the first submission, and second, the number of submissions. The lateness of the first submission is moderately negatively correlated with performance, and the number of submissions is weak-to-moderately positively correlated with performance. However, neither variable explains a large portion of the total variance even when both are used in multiple regression.

In conclusion, there seems to be a difference between students who achieve mastery and students who do not achieve mastery. Students who achieved mastery performed better and more predictably than students who did not. However, elements of mastery seem to have not been captured by this study. The proxy variables for measuring mastery did not produce high R^2 scores.

Discussions and Future Work

The introduction of course mechanisms to facilitate mastery learning was helpful but incomplete. Some students did not take advantage of the mastery learning facilities. With indication that there is a relationship between mechanisms for mastery learning and learning outcomes but also an understanding that there are remaining but unidentified factors inhibiting taking advantage of these mechanisms, what classroom policies are needed to maximize mastery learning?

Future work may consider conducting qualitative analysis on why students choose not to take advantage of multiple submissions. Succeeding studies (observation or experiment) may involve other sections of the same subject but not follow the multiple submission policy. Future course designs may also include submission mechanics to induce and encourage submissions as early as possible. It may also be worthwhile exploring the gating approach done by McCane, Ott, Meek, & Robins (2017). Finally, the possibility and significance of external help or, worst case, academic dishonesty, needs to be addressed.

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