

Steps Towards a Mastery Learning Approach in Mathematics Service Teaching

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Mastery Learning is based on a belief that all students can achieve the same level of content mastery when provided with sufficient time and appropriate resources. We report on an initiative to adopt elements of a mastery learning approach in a first year undergraduate Calculus module for students on Chemistry and Biology programmes, facilitated by digital technology. These included administering a pre-teaching diagnostic assessment, offering regular formative assessments and providing opportunities to retake summative assessments. We discuss students' responses to these additional opportunities to succeed in terms of uptake, improved outcomes and the perceived usefulness of the approach.

Keywords: mastery learning, Calculus, service teaching

Introduction

Since the 1960s many educators have developed instructional programmes around the notion of 'mastery learning'. Bloom stated that

Most students, perhaps over 90 percent, can master what teachers have to teach them, and it is the task of instruction to find the means which will enable students to master the subject under consideration (Bloom, 1968, abstract).

He believed that the cornerstone to the achievement of mastery is the provision of whatever time is needed by each student for learning and that 'instructional alternatives' (in the form of different resources) should be made available to enable each student to learn to a high level. Two particular approaches to mastery have been adopted widely: Learning for Mastery (LFM) (Bloom, 1968) and Personalised Systems of Instruction (PSI) (Keller, 1968). While each includes the division of content into short units with formative assessments to be completed on each unit, they also differ in important aspects. LFM lessons are presented by teachers and thus students move through them at a uniform pace; whereas PSI lessons are typically presented using written materials through which students move at their own pace, revising the content and retaking assessments until they demonstrate the desired level of mastery. As Guskey (2010) explains, allowing students to retake assessments, which is essentially offering them a second chance to succeed, serves as a powerful motivational tool. In addition, the inclusion of regular formative assessments, a core element of mastery learning models, allows students' progress to be monitored systematically and regular feedback to be given, realising assessment *for* learning. Another common element of mastery learning programmes is the administration of a diagnostic (pre-)assessment pre-teaching to determine whether students have the prerequisite knowledge and skills to succeed on the programme (Guskey, 2010). Students whose preassessment scores suggest deficiencies in their foundational knowledge are then given the opportunity to remediate them before continuing with the programme.

In a meta-analysis of findings from 108 studies, Kulik et al. (1990) reported that mastery learning programmes have positive effects on the achievement of students (at all levels) on examinations as well as on their attitudes to both course content and instruction. Moreover, the weaker students in a class appear to benefit more from such an approach. Groen et al. (2015) also report the positive effect of mastery learning on retention of content. However, the amount of time spent by students on instructional tasks may increase, and self-paced mastery programmes may reduce the completion rates of those on college level programmes (Kulik et al., 1990).

More recently, digital technologies have been used to design adaptive learning platforms, which aim to adapt instruction and assessment to individuals' prior knowledge, educational experience and interests (Aleven et al., 2016). These have the capacity to incorporate elements of the LFM and PSI approaches outlined above in an efficient manner.

Rationale & Aims

Much of mathematics is hierarchical in structure, with later concepts and skills building on earlier ones. Consequently, learning in mathematics must often progress through a structured sequence in which some items of knowledge or skill are necessary prerequisites to subsequent ones. Furthermore, mathematics underpins a wide range of STEM learning activities. Despite this, the under-preparedness of incoming students for the mathematical demands of their undergraduate programmes has been widely (across Ireland, the UK, the US and Australia) and long since reported – a phenomenon regularly referred to as the 'Mathematics Problem' – and in fact, appears to be worsening (Treacy & Faulkner, 2015). Even though students may pass university mathematics modules with a grade of 40%, there is anecdotal evidence of a belief among mathematics educators that such a level of competence does not provide an adequate foundation for the future learning of related mathematical concepts nor ensure the ability to apply mathematical knowledge across STEM disciplines.

We wished to increase the competencies of first-year undergraduate science students on our mathematics modules and better prepare them for subsequent mathematics and STEM modules by encouraging and enabling them to master the content rather than to merely achieve a passing grade. However, our capacity for innovation was somewhat constrained by the large number of students (circa 400) taking the modules in question.

Instructional Approach & Methodology

In 2021, we embarked on the redesign of service Calculus modules for first-year undergraduate students on DCU's science programmes incorporating features of both the LFM and PSI models. We adopted a blended-learning approach, utilising DCU's virtual learning environment (VLE) Loop, which allowed us to be flexible and adaptive in terms of variety of and access to materials, and facilitated the provision of individualised pathways through the module to accommodate a diversity of learners. Content is organised into four main units (Pre-calculus, Limits, Derivatives and Integrals) and delivered using (short) pre-recorded videos interspersed with interactive questions. Each week clear instructions are provided to students with regard to the activities and resources with which they should

engage, including weekly formative assessment quizzes (which provide instant feedback to students) and recommended reading from a Calculus textbook. These are supplemented by face-to-face Q&A sessions and face-to-face small group tutorials. A diagnostic pre-assessment is administered before the module begins to ascertain whether students have the necessary foundational knowledge (e.g. from algebra, trigonometry etc.) to enable them to complete the module successfully. If gaps are detected for a particular student, he/she is directed to additional video and written resources addressing those gaps before retaking the pre-assessment. This extra material (the Foundations Unit) is made available over the first few weeks of the module while the module itself proceeds at a reduced pace during this period to allow students time to engage with this revision material. Course credit was awarded for completion of the pre-assessment tests (Ní Shé et al., 2023).

Summative assessment comprised various components including Loop quizzes on the four units over the duration of the year-long module (accounting for 40% of the module grade), with the option of taking each one a second time after a specified interval (typically one week). These quizzes were timed (25-35 minutes) and were available over a 6–8-hour window. Students were provided with automated feedback on their attempts on the tests and were supported to learn content or develop skills in a number of ways before being tested again (by taking an alternative form of the test). Firstly, all resources provided online remained available to students for the duration of the module to allow students to review and revise the material as appropriate and to study at their own pace. Queries could be raised by students in the weekly Q&A session or tutorial about questions they had difficulty completing. Students were also referred to DCU's Mathematics Learning Centre for additional support from a mathematics tutor. This approach is in the spirit of the remediation process reported in Howard et al. (2019) and has similar aims: to allow students to improve based on feedback received.

The data on which we report here was collected for the academic year 2023/24 for 252 students taking the module MS150 Calculus & its Applications, following ethical approval. This module was mandatory for all first year Biology, Chemistry and Environmental Science students (excluding students on the Genetics and Cell Biology programme) at DCU. In 2023/24, there were six Loop quizzes (LQ1-6) with two quizzes on each of the two final units of content (LQ 3,4; LQ5, 6) as these covered more material. The numbers of students taking tests on Units 1-4 at each opportunity and the score associated with each attempt were recorded in Loop. This data was then collated, summarised and analysed using MS Excel. In addition, students were asked to complete a short online survey on completion of the module. This included a number of Likert scale items to collect information on their experience of the module. The survey was administered using a Google form which also collated and summarised the responses collected.

Our research questions were the following: Did students find the mastery learning approach taken (vis-à-vis formative assessments, Foundations Unit material, retake opportunities for summative assessments) useful? Did students availing of the retake opportunities provided for the quizzes improve their performance?

Results

Table 1 below show students' engagement with the two opportunities provided to complete each of the Loop quizzes and their levels of achievement. For students who attempted the quiz at both opportunities, Table 2 indicates the percentage whose score increased on taking a particular quiz for the second time and the average increase in score realised.

Table 1

Average % score on each test and number of student attempts

	LQ1	LQ2	LQ3	LQ4	LQ5	LQ6
1 st opportunity	44% (#244)	59% (#237)	61% (#226)	72% (#192)	77% (#205)	72% (#216)
2 nd opportunity	55% (#117)	60% (#103)	59% (#84)	75% (#98)	70% (#66)	73% (#90)
Best of 1 st & 2 nd opportunities	55% (#245)	65% (#250)	67% (#236)	78% (#242)	79% (#236)	79% (#244)

Table 2

Percentage of students whose score increased on second attempt at quiz and average absolute increase in score (out of 100)

	LQ1	LQ2	LQ3	LQ4	LQ5	LQ6
Percentage of students	70	65	68	79	51	66
Average increase	32	30	41	39	38	42

At the end of the module, students were asked to complete an online survey on their experiences of the module. As part of this, Likert scale items asked them to rate their agreement with the following statements:

- I found the *Foundations Unit* useful for bringing my basic mathematical skills to the right level.
- I found the weekly *formative assessment quizzes* useful.
- I found the *resit opportunities* for many components of continuous assessment useful.

Table 3 below shows the number of students responding to each of these items and the distribution of responses received.

Table 3

Distribution of responses to Likert scale items on usefulness of formative assessment quizzes, Foundations Unit and resit opportunities for summative assessment quizzes

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
<i>Foundations Unit</i> (152 responses)	28	60	44	11	9
<i>Formative assessment quizzes</i> (152)	38	66	43	2	3
<i>Resit opportunities</i> (153)	94	38	18	3	6

Discussion

132 of 159 (or 83%) of respondents strongly agreed or agreed that they found it useful to be able to resit the summative Loop quizzes showing the degree to which they appreciated this initiative and the ‘second chance to succeed’ it afforded them (Guskey, 2010). This is further supported by the evidence provided in Table 1 of the number of students availing of these resit opportunities. However, their engagement with the second attempts can be seen to decrease, though not uniformly, over time (LQ1-5) suggesting that a weariness or apathy with the assessment structure may have set in. An increase in the numbers of students attempting LQ6 was observed for both sittings, but this may be explained by the fact that it was the last such quiz and thus provided one of the final opportunities for students to improve their overall module grade. In addition, for each quiz, the majority of students who availed of the opportunity to resit were able to improve on their grade (Table 2) and the average increase in score achieved by these students was evident. These increases indicate that the “correctives were successful in helping students remedy their individual learning difficulties” (Guskey, 2010, p.54) for those students at least. Furthermore, there was no evidence that students had a sense of being taught how to pass a test rather than developing a greater understanding and level of skill through the module, as was reported by Groen et al. (2015) as a negative outcome of their implementation of mastery learning.

Boggs et al. (2004) reported that two major obstacles often inhibit the use of mastery-learning as an instruction method – namely, grading multiple versions of tests at various stages of a course and scheduling time for test re-takes. As suggested by Alevén et al. (2016) technology allowed us to address these barriers and support adaptivity in ways that had previously been difficult for teachers to manage. Using the Loop VLE we were able to create multiple versions of quizzes quite easily by means of its randomised question and wildcards within questions features; Loop also facilitated automated grading and the provision of feedback. Moreover, the online nature of the quizzes relieved the pressure on scheduling.

Students also found other elements of the mastery learning approach useful. 104 of 152 respondents (or 68%) found the formative assessments useful, while 88 (or 58%) found the Foundations Unit useful. The inclusion of these elements in the module aims to create the conditions necessary for students to succeed by (i) ensuring students have the necessary prerequisite skills and (ii) monitoring student progress and providing prescriptive feedback throughout the module. Guskey (2010) asserts that research has consistently linked these elements of a mastery learning approach to highly effective instruction. The improvements recorded in Table 2 above reflect findings of Howard et al. (2019) – and raise corresponding

questions, which we will address elsewhere. The overall impact on attainment levels in the module, and retention of knowledge is contentious.

Groen et al. (2015) report that mastery learning has been shown to be useful in addressing and counteracting the 'Mathematics problem' for many STEM students at an Australian university. The implementation of a mastery learning approach offers similar benefits at Irish universities at a time when the mathematical under-preparedness of incoming students continues to be problematic.

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