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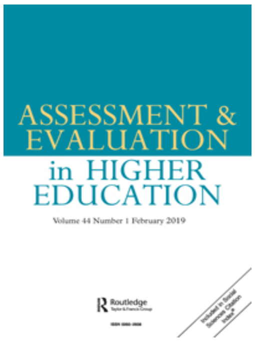

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Quantifying participation in, and the effectiveness of, remediating assessment in a university mathematics module

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ABSTRACT

In *Maths for Business*, a large first-year mathematics module, the continuous assessment component comprises 10 weekly quizzes which combine to contribute 40% of the final module mark. If students did not receive the full five marks on their weekly quiz, they were provided with the opportunity to resubmit their corrected weekly quiz with an explanation of their error(s) for one additional mark. We refer to this process as 'remediation'. Of the students who had the opportunity to remediate, ~70% did. Through examining learning management system data, we show that the remediation process encouraged students to access module resources. Furthermore, by using a Bayesian hierarchical model to account for students' level of participation, achievement and prior knowledge, we show that participation in the remediation process positively impacted the final examination marks of moderate to high-achieving students (based on initial continuous assessment marks). However, participation in the remediation process provided limited benefit to low-achieving students. We conjecture this is because these students had not achieved a level of understanding whereby participation in the remediation process could progress their knowledge.

KEYWORDS

Undergraduate mathematics; assessment; feedback; resubmission intervention

Introduction

In her review of the research literature on assessment feedback in higher education, Evans (2013) observes that its benefit to students remains an open question. However, before evaluating the impact of assessment feedback on students' learning, the level of student interaction and engagement with the feedback should be considered. Gibbs and Simpson (2004) highlight that, even when informative and timely feedback is provided to students, they may not engage with it.

In this article, we present a process designed to incentivise student interaction with feedback in a large, first-year, undergraduate mathematics module for business majors called *Maths for Business*. Students in this module have the option to attend face-to-face lectures or watch online videos (or both). However, in an attempt to encourage consistent engagement with the learning outcomes, all students are required to take a weekly, closed-book, 15-min quiz. Each quiz is worth 5%, and the continuous assessment component of the module (worth 40%) comprises a student's best eight quiz marks, out of a possible 10 quizzes. In the academic year 2016–2017, in order to encourage students to review and remediate any errors made on a quiz, we introduced

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a 'remediation process'. Students who did not receive the full five marks on their quiz were incentivised to resubmit their quiz 1 week later, with a description and correction of their error(s), in order to gain one additional mark.

Our primary motivation for introducing the remediation process was to encourage students to identify and learn from their errors in a timely manner. The module covers topics from calculus with applications to business, and the content is cumulative in nature. Therefore, failure to master a learning outcome early in the semester may cause students persistent problems for the remainder of the module. Students were encouraged to use whatever resources they wished in order to remediate a quiz, be it one of the module feedback resources (which are elaborated upon later), or attending the Mathematics Support Centre, or seeking help from a friend.

We are interested in examining which students are most likely to participate in the remediation process, what resources (if any) they access in doing so, and, perhaps most importantly, whether participating in the process results in learning gains as measured by their performance in the final 2-h, closed-book, examination for the module. For these reasons, we attempt to address the following research questions in this article:

1. Which students are most likely to participate in the remediation process?
2. Which resources are accessed by students participating in the remediation process?
3. Does participation in the remediation process result in improved achievement in *Maths for Business* as measured by final examination performance?

The remediation process had a high participation rate, with ∼70% of students who could remediate using the opportunity to do so. Participation varied, with students who initially received high marks on their quiz more likely to remediate. From examining Blackboard data, we found students did review the pdf solutions of the quizzes; however, their access of other module resources for the remediation process was limited. Unlike other studies (Covic and Jones 2008; Fisher, Cavanagh, and Bowles 2011), we avoid relying on *t*-tests which do not consider explanatory coefficients, or classical regression which does not account for group-level variation. For our analytical framework, we developed a Bayesian hierarchical model to examine in detail the impact of participation in the remediation process on performance while controlling for students' continuous assessment marks and prior knowledge (identified by Shute (2008) as important variables in the effectiveness of formative feedback).

We show that participation in the remediation of quizzes positively impacts students' performance, in particular for students with high continuous assessment marks. Other factors identified in our literature review as important for effective feedback (subject domain, frequency, timing and type of feedback), while not included in the Bayesian model, are discussed in the context of the remediation process.

Literature

Assessment and feedback

There have been a number of prominent reviews in the area of assessment and feedback (Sadler 1989; Shute 2008; Black and Wiliam 2009; Evans 2013), which highlight the varying terminology associated with assessment; an issue emphasised by Cookson's (2018) analysis of assessment terminology. Evans (2013, 71), who focuses solely on literature in higher education, uses assessment feedback in a broad sense to mean 'all feedback exchanges generated within assessment design, occurring within and beyond the immediate learning context, being overt or covert (actively and/or passively sought and/or received), and importantly, drawing from a range of resources'. Generally, assessment is considered under two headings (Sadler 1989; Bennet 2011): summative assessment (primary motive is evaluating students' knowledge of material, often at the end of a module), and formative assessment (primary motive is improvement in students' learning). Following from this, formative feedback is information which is communicated to learners in order to improve their understanding (Shute 2008), although some studies argue that feedback must improve student learning for it to be counted as feedback (Evans 2013).

Students' achievement levels and prior knowledge, in addition to the task level of the assignment/assessment, are factors which influence the effectiveness of formative feedback (Shute 2008). Trenholm, Alcock, and Robinson (2015) state that the two characteristics of type and timing of feedback have the most impact on its effectiveness, with other important variables including specificity and frequency of feedback and the topic/domain of interest. In comparison, Carless et al. (2011) consider type and timing of feedback as minor, or possibly trivial factors – instead they consider student self-regulation to be the central factor of feedback processes. According to Pintrich and Zusho (2002, 64), self-regulated learning can be defined as 'an active constructive process whereby learners set goals for their learning and monitor, regulate, and control their cognition, motivation, and behaviour, guided and constrained by their goals and the contextual features of the environment'. Nicol and Macfarlane-Dick (2006) expand on self-regulation in practice, identifying factors (setting, resource management, strategies for learning goals, etc.) which are part of student self-regulation.

A lack of specific domain-focused reviews of assessment has been noted in the literature, including assessment in undergraduate mathematics (Bennet 2011; Iannone and Simpson 2013). In regard to assessment in undergraduate mathematics modules, Trenholm, Alcock, and Robinson (2015) remark on the emphasis placed on summative assessment in face-to-face modules. Iannone and Simpson (2011) support this, highlighting that the dominant form of assessment in university mathematics courses is the closed-book examination, with project-based and other forms of assessment being more limited. However, in their study on student perceptions, Iannone and Simpson (2013) found mathematics students prefer summative assessment methods, which contrasts to the general literature where students prefer alternative assessment methods.

Participation with feedback

There has been recognition that, despite timely and informative feedback being provided to students, they may not engage with it (Gibbs and Simpson 2004; Handley, Price, and Millar 2011). Handley, Price, and Millar (2011) call for researchers to switch from evaluating feedback to investigating students' level of engagement with it. Studies examining the benefits of resubmission interventions have had mixed results, and students often do not avail themselves of such opportunities (Evans 2013).

Covic and Jones (2008) provided psychology students with the opportunity to resubmit their corrected essay assignments (worth 20%) for higher marks. After the initial submission, students received an initial grade, detailed individual feedback and general group feedback. This was a voluntary process where students had 2 weeks to resubmit. Forty-eight percent of the 54 students availed themselves of the opportunity. In comparison, Fisher, Cavanagh, and Bowles (2011) investigated providing business students with detailed feedback on their draft essays (prior to marking), and had a 19.7% participation rate for 539 students. Covic and Jones (2008) and Fisher, Cavanagh, and Bowles (2011) use descriptive statistics, *t*-tests, Cohen's *d* and qualitative analysis to evaluate the effectiveness of their two-stage assessment, with both studies finding that the majority of students who participated achieved improved module performance.

However, null hypothesis statistical testing fails to take into account other variables and is often misused. Common misinterpretations are concluding that the failure to reject the null hypothesis provides confirmation of it (Kline 2013), and the misleading terminology that 'statistical significance' indicates importance of a result (López et al. 2015). Comparatively, Chen, Breslow, and DeBoer (2018) examined the level of engagement physics students had with a simple green tick or red cross (yes/no) feedback for questions and identified, using log-files, online resources accessed immediately after feedback was provided. To analyse the impact of this feedback, they defined appropriate measures of interaction, conducted statistical analysis, including *t*-test, multiple linear regression, correlation analysis, agglomerative hierarchical clustering, K-means clustering and multiple linear regression with least absolute shrinkage and selection operator variable selection. Students who used the feedback provided, in combination with self-regulated techniques, performed better in the module.

A common notion in the literature is the feedback gap, whereby there is a misalignment between students and lecturers' perception of feedback (Carless 2006; Evans 2013). Considering students' use of feedback, Handley, Price, and Millar (2011, 557) emphasise the difference between the student who skims and bins the feedback and one who 'takes responsibility for understanding, interpreting and applying assessment feedback'. While it is the students' choice to engage with feedback, students may not have the relevant experience to use it effectively (Evans 2013). Price, Handley, and Millar (2011, 892) discuss how 'it is very often student's means to apply feedback that is overlooked. Rejection of feedback advice may be due to lack of understanding, or based on identity or self-efficacy issues preventing the student taking action'. They further suggest that students may need more support and help to act on the feedback. The feedback needs to be of an appropriate level to help the student; considering the student's current level and the level which they can achieve with support.

Data and data collection

Maths for Business *and the remediation process*

Maths for Business is a first-year mathematics module taken by ∼500 business majors in University College Dublin. The module is offered in the first semester which consists of 12 weeks of lectures, one revision week and 2 weeks of examinations. The content of the module consist mainly of topics from calculus and applications to business are emphasised. Students in *Maths for Business* can complete the course through face-to-face lectures and/or online videos. Students may also avail themselves of mathematics support consisting of one-to-one or small-group support through the university Maths Support Centre, and/or a dedicated three-hour drop-in session each week exclusively for *Maths for Business* students. These fall under the umbrella term of Maths Support Centres.

Assessment for the module comprises of 10 weekly quizzes examining learning outcomes from each week, and a 2-h, closed-book examination, which may examine all learning outcomes. These assessment components are worth 40 and 60%, respectively, of the final overall mark for the module. The rationale behind the weekly quizzes is to encourage consistent engagement and motivate mastery of the weekly learning outcomes. Each 15-min, closed-book quiz is worth 5%, and the continuous assessment component of the module comprises a student's best eight quiz marks out of a possible 10 quizzes.

The quizzes are administered to tutorial groups of 50 students by teaching assistants who also correct the written submissions and return them to students 1 week later. Weekly assessment feedback is provided in a number of ways: student receive a summative quiz mark out of five; oral feedback highlighting common errors made by the entire cohort is provided to each tutorial class by their teaching assistants on return of the graded quizzes; a pdf of the quiz solutions which also contains recommendations for relevant online videos, which students may review, is made available by the lecturer on Blackboard; and, the lecturer makes a video highlighting common errors and recommending online videos for review, which she also posts on Blackboard.

In the academic year 2016–2017, in order to encourage students to review and remediate any errors made on a quiz, we introduced a 'remediation process'. Students who did not receive the full five marks on their quiz were incentivised to resubmit the quiz with a description and correction of their error(s), in order to gain one additional quiz mark. Our primary motivation for introducing the remediation process was to encourage students to identify and learn from their errors in a timely manner. Students were meant to self-diagnose and learn from their errors, and not simply reproduce the solution. The students had 1 week from receiving their corrected quiz to resubmitting their remediated quiz.

This idea has its origins in Bloom's mastery learning (Bloom 1984), whereby students have the opportunity to learn from their mistakes and master the material before continuing their studies to more advanced material. When deciding upon this format, we considered awarding marks on a sliding scale based on the initial quiz mark received. This would account for the difference in effort needed for a quiz remediation between a low initial mark versus a high initial mark (e.g. a 0/5 initial mark in comparison to a 4/5 initial mark). However, this complicates the remediation process and would require further time and effort from the teaching assistants. The format of the remediation process required a balance between the effort required by teaching assistants and the additional submissions by students.

The following is an example of the remediation time-frame: students complete quiz 1 on the 27th of September. On the 4th of October, students complete quiz 2 and their teaching assistants return the corrected quiz 1. All the feedback resources (listed above) for quiz 1 are made available. On the 11th of October, students submit their remediated quiz 1, receive their corrected quiz 2, and complete quiz 3. Quizzes commence on the third week of term, and due to the 12-week teaching period and the fortnightly remediation cycle, students only had the opportunity to remediate the first eight quizzes. Students were informed that they must have attended the quiz to be eligible to remediate it, and that their remediated quizzes would not be returned to them. For revision purposes, we recommended to students that they photocopied their remediated quizzes before resubmitting them. We collected the remediated quizzes in order to perform a qualitative analysis on approaches taken by students to remediate. To date this has focused on whether students completed a three-step approach of having identified, described and corrected their error(s).

The following instructions were provided to students as a guide to how to remediate a quiz:

1. When your quiz is returned to you go over it and identify your errors. Write a sentence beside each error on the quiz sheet so that when you are revising the material again, you will have a note to yourself about where you went wrong.
2. If it is the case that your errors were more than just a 'slip', then you should write out the correct solution on the quiz sheet and write a sentence or two beside the solution summarising the method.
3. You should use a different coloured pen so that the tutor can clearly distinguish between what you wrote in the quiz and your remediation comments.
4. Imagine you are correcting your friend's quiz and you are explaining to your friend where he/she went wrong.

Data collection

In the assessment literature, there has been acknowledgement of the interaction between formative feedback and student achievement level, task level and prior knowledge (Shute 2008). Prior studies of *Maths for Business* (Howard, Meehan, and Parnell 2017) suggest that students' prior knowledge influences their use of module resources and academic attainment levels. As a proxy for prior mathematical knowledge, we consider the numeric variable of Leaving Certificate mathematics points. The Leaving Certificate is the terminal post-primary examination which the majority of Irish students take, and it determines entry to university courses. The grades awarded for the Leaving Certificate mathematics examination are also assigned a numeric value on a scale of 0–100. Recently a new marking scheme was introduced into the Irish educational system, however here we use the pre-2017 marking scheme (Baird et al. 2014). The Leaving Certificate is divided into three levels, Higher Level, Ordinary Level, and Foundation Level; however, the minimum entry requirement for *Maths for Business* is a mark of at least 40% in Higher Level or at least 70% at Ordinary Level.

In 2016–2017, we collected the following data for each *Maths for Business* student: demographic data including gender, year of study and whether the student was repeating the module; weekly quiz marks (before remediations); number of remediations engaged in by the student; final examination mark; lecture attendance via barcode scanning of the student card; students' online activity with Blackboard via log files; and attendance at any Maths Support Centre via their electronic records. In order to obtain as accurate a measure as possible for prior mathematics achievement, we only included students if they had taken the Leaving Certificate State Examination for Mathematics, and we could include their mathematics result in the data. We collated the electronic data for each student under a pseudo ID number.

For a student to be included in this study, they had to be taking the module for the first time (non-repeating student) and must have attended at least six of the first eight quizzes. Our rationale for this is that even if they missed two of the first eight, they could still take the final two quizzes and the marks from all eight quizzes could count towards the student's continuous assessment score. Finally, we only included students who took the final examination in the module as this was an indicator of having completed the module and also provided us with a measure for student learning. Considering all of these factors, 405 students from the 2016/17 cohort were included as participants. This study was completed with the approval of University College Dublin ethics committee under the application number LS-16-48-Howard-Meehan.

Definitions

To assist with our analysis, we define measures for a student's participation with the remediation process (the eight quizzes that they could remediate):

$$\text{Remediations possible} = \text{Number of quizzes attended where less than full marks was achieved}$$

$$\text{Percentage of quizzes remediated} = \frac{\text{Total number of remediations completed}}{\text{Total number of remediations possible}} \times 100$$

Statistical analysis

Rationale and description of the model

In order to address the third research question of how students' level of participation in the remediation process impacted their final examination mark (no continuous assessment is included in this mark), we created a Bayesian regression model with the response variable of final examination mark and the explanatory variable of percentage of quizzes remediated, incorporating a factor level for total number of remediations completed. However, on reflection we realised that this created unfair comparisons between students. For example, a student who may have received 4/5 marks on the first eight quizzes, would have been compared to a student who had received 0/5 on the same quizzes. We disaggregated these data to take account of the difference in work needed to remediate different quizzes and also to allow students of similar ability to be compared. Students' average quiz marks (excluding remediation marks) for the first eight quizzes were divided into four groups: 0–2 marks, 2–3 marks, 3–4 marks and 4–5 marks. The number of students in each group, starting with the lowest continuous assessment range, was 52, 100, 169 and 84, respectively. To benefit from this grouping, we created a Bayesian hierarchical/multilevel model. Hierarchical models have several advantages over classical regression as they allow for information to be shared among groups, provide estimates of group-level coefficients, and account for individual-level and group-level variation in the regression coefficients (Gelman and Hill 2007). By not accounting for the hierarchical structure in data, standard errors of regression coefficients may be overestimated which can lead to an overstatement of statistical significance.

For our model, rather than using the null hypothesis significance testing approach, we chose to follow a Bayesian approach. Bayesian analysis is composed of statistical methods which allow for prior knowledge or assumptions about parameters of a distribution to be combined with information provided by data to produce a posterior distribution. By using a Bayesian approach, we can account for uncertainty in our coefficient estimates by providing credibility intervals for our parameters. Further advantages of Bayesian methods include handling uncertainty in small datasets, more flexibility in comparison to classical methods, and the full posterior is defined rather than the 'best value' being provided. The disadvantages of using Bayesian models can be the high computational cost and an inappropriately chosen prior distribution heavily influencing the posterior distribution. In cases with larger datasets, the prior distribution has less of an effect.

Our model contains two factor levels: factor level-1 is the individual student and factor level-2 is the average quiz mark grouping ($j \in \{1,2,3,4\}$). We considered several models (Table 1) with explanatory variables including total number of lectures attended, total number of videos accessed and total number of visits to the Maths Support Centres, as well as models with interactions. In this article, we present the best statistical model found based on deviance, convergence of Markov chains and diagnostic checks. We use the following notation in our modelling:

Y_{ij} = examination mark for student $i \in \{1, \dots, N_j\}$ in $j \in \{1,2,3,4\}$ average quiz mark group

X_{1i} = percentage of quizzes remediated for student $i \in \{1, \dots, N_j\}$

X_{2i} = mathematics points for student $i \in \{1, \dots, N_j\}$

β_{0j} & β_{1j} & β_{2j}: Intercept and coefficient parameters to be estimated for each $j \in \{1,2,3,4\}$ average quiz mark group

Likelihood for $i \in \{1, \dots, N_j\}$ and $j \in \{1,2,3,4\}$:

$$Y_{ij} \sim N\left(\beta_{0j} + \beta_{1j}X_{1i} + \beta_{2j}X_{2i}, \sigma^2\right)$$

Priors used in the hierarchical model: β_{0j} & β_{1j} & $\beta_{2j} \sim N(\mu k, \sigma^2{}_{QM})$ for k = {1,2,3} μ_0 & μ_1 & $\mu_2 \sim N(0, 100)$ σ & $\sigma_{QM} \sim$ half-cauchy (0, 10)

The normal distribution with a wide variance is chosen for the prior on the intercept and variable coefficients as it is considered minimally informative. Minimally informative priors have limited influence on the posterior distribution and allow the likelihood function or the data to dominate the posterior distribution. We have chosen minimally informative priors as we have found very limited literature for Bayesian models in assessment and feedback with which to provide informative information. The half-cauchy is chosen as the prior on the residual standard deviation (σ) and standard deviation between groups (σ_{QM}) as it limits the standard deviation to positive values, performs well near the origin, has a gentle slope in the tail (unlike the normal distribution) and is suitable for a small number of groups (Gelman 2006).

Model estimation, convergence and fit

For our study, we use the R package, R2JAGs (Su and Yajima 2017) to create and run our Bayesian hierarchical model. The code is available on GitHub at: https://github.com/ehoward1/Hierarchical-Model. The model was run using 8000 iterations with four chains and 2000 burn-in values per chain. We assessed the convergence of the algorithm by viewing the Markov Chain plots of the parameters, checking for autocorrelation, and ensuring that the potential scale reduction factors are ~1. Furthermore, the effective sample size for each value was above 400. To assess our best model, we relied on contrasting the deviance of the models, and subsequently considered the residuals produced.

Table 1. A sample of the alternative models considered to the model discussed in the article with their corresponding DIC values for comparison. The lowest DIC (highlighted in bold) indicates the best model examined.

Model	% Remediated	Maths points	No. lectures	No. videos	Centre visits	No. solutions	DIC
1	Yes	Yes					**3233**
2	Yes		Yes				3302
3	Yes			Yes			3307
4	Yes				Yes		3305
5	Yes					Yes	3310
6	Yes	Yes	Yes				3267
7	Yes	Yes		Yes			3417
8	Yes	Yes			Yes		3242
9	Yes	Yes				Yes	3257
10	Yes		Yes	Yes			3310
11	Yes	Yes	Yes	Yes			3266
12	Yes	Yes		Yes		Yes	3292
13	Yes		Yes	Yes	Yes		3316
14	Yes		Yes		Yes	Yes	3321
15	Yes	Yes	Yes	Yes	Yes	Yes	3267

Results

RQ1: Which students are most likely to participate in the remediation process?

In response to our first research question, we investigated the percentage of students who remediated out of those who had the opportunity to do so (see Figure 1). Throughout the semester, there was a low participation rate by students who obtained low scores (<2 marks) on a quiz. In theory, the lower the initial mark on the quiz, the more time and effort is involved in remediating a quiz. There was no difference in the percentage remediated between students who completed the Higher Level Leaving Certificate mathematics ($\bar{x} = 68\%$, $s = 28\%$) and those who completed the Ordinary Level mathematics examination ($\bar{x} = 69\%$, $s = 24\%$). Overall, ∼70% of students who could remediate weekly chose to do so.

When we compare the percentage of students remediating on a specific quiz to the average initial mark on the quiz, there appears to be a positive correlation. The quiz with the lowest average mark, quiz 6, had the lowest remediation percentage of 55%, and the quiz with the highest average mark, quiz 1, had the highest remediation percentage of 77%. While this pattern persists for the other six quizzes, other factors may be influencing this relationship, including the nature of the quiz questions. For example, provisional qualitative analysis suggests students achieved lower marks on conceptual questions (including both questions in quiz 6) in comparison to procedural questions. Alternatively, as students' continuous assessment consisted of their best eight quizzes, students may not have remediated upon achieving a lower mark than usual, or competing assignments in other modules may have impacted on their decision to remediate or not.

RQ2: Which resources are accessed by students participating in the remediation process?

For this, both Maths Support Centres attendance and Blackboard usage were recorded. Analysis of the Blackboard records indicates pdfs of the quiz solutions were the main resource accessed to remediate the weekly quizzes. Video solutions were a minor resource for students. We consider students having reviewed the resource in a timely manner if they accessed the resource within the remediation time period, which is within a week of receiving their corrected quiz. We contrast views of relevant remediation resources (pdf solutions and relevant videos) for quizzes 1–8 in respect to quiz 9 and 10 (where remediation was not an option).

Figure 2 shows the difference in the percentage that viewed the relevant quiz solution within a week between a remediated quiz and a non-remediated quiz. The increase in percentage from quiz 9 to quiz 10 may have occurred owing to revision week. In revision week, students' use of

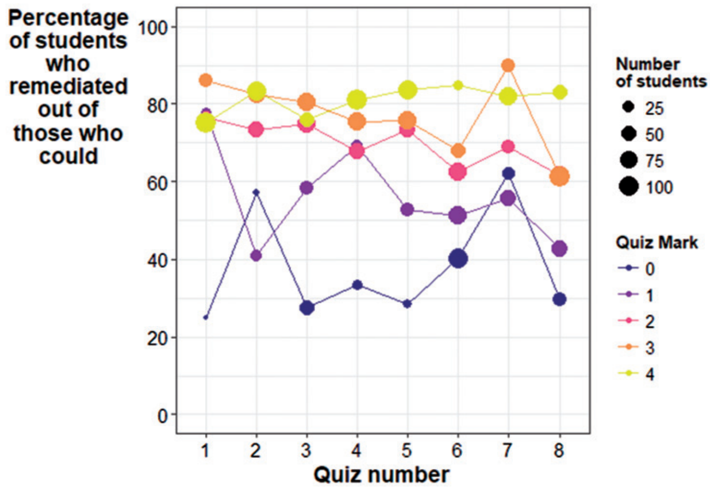

Figure 1. Of those students who could remediate, the percentage of students who did remediate grouped according to their quiz number and quiz mark received. For example, on quiz 1, four students scored zero out of five. Of these four students, 25% remediated. Also, for quiz 1, of the 108 students who scored four on the quiz, 75% remediated.

all module resources increased substantially, for example, all quiz solutions were reviewed ∼230 times. In the quiz solution pdfs, each question of the first six quiz solutions was linked to a recommended video(s). The recommended video is the *Maths for Business* video which contains the module content required to address the relevant quiz question. Surprisingly, these videos had limited number of accesses during the remediation period, with only 17 students accessing recommended videos in more than one remediation period.

Students were encouraged to use the Maths Support Centres if they were experiencing difficulties, in particular students who received a low quiz mark of zero or one. The number of visits to the Maths Support Centres for *Maths for Business* increased from 303 in 2015/16 to 402 in 2016/17; however, the attendance is low relative to the module size. An examination of the attendance records shows that very few students used it as a resource to help with their remediations. Students may have also used tutor feedback or asked friends for assistance. As we did not collect student feedback on these, we cannot explore this further.

RQ3: Does participation in the remediation process result in improved achievement in Maths for Business as measured by final examination performance?

To answer our third research question, we initially contrasted the distribution of the final examination marks with the same distribution from the prior academic year. Overall there was a decrease in marks. However, we argue this is a crude comparison owing to natural fluctuations in marks and/or changing factors, for example different student cohorts, different final examinations etc. In order to investigate whether participating in the remediation process improved students' final examination mark, we compared students' percentage remediated versus their final examination mark ($r = 0.28$). To allow for students of similar continuous assessment to be compared, we developed a two-level hierarchical model with a response variable of final examination mark and two explanatory variables of percentage remediated and leaving certificate mathematics points.

Participation in the remediation process did not help all students equally (see Figure 3). There is more uncertainty in the credibility intervals for low-achieving students (wider credibility intervals), with the intervals including coefficient estimates of zero as well as the highest coefficient values. A zero coefficient would indicate that the remediation process did not affect students' examination marks in any manner. The highest mean coefficient estimate was for the 4–5 marks

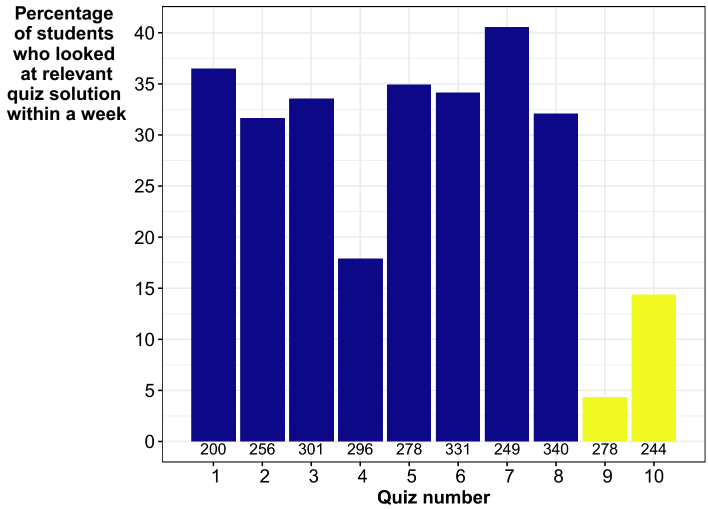

Figure 2. Of those students who could remediate, percentage of students who accessed the relevant quiz solution within 1 week of having their quiz returned. The number of students who could remediate for each quiz is indicated at the bottom of each bar.

group with an estimate of 0.166 meaning that a student who remediated 100% would have achieved on average 16.6% more in their final examination than a student who did not remediate in the same group (with the same mathematics points). The largest group of students achieved on average 3–4 marks ($n = 169$) and had the narrowest credibility interval with a high mean value of 0.151. The narrow credibility interval suggests the model is confident that the participation in the remediation process helped these students, and arguably supported this group of students the most. Figure 4 shows the examination mark plotted against the percentage remediated for the 3–4 mark group. The coefficient estimates (Table 2) for the second explanatory variable of Leaving Certificate mathematics points were higher for each level (mean of 0.353–0.756); however, while these dominate predictions, our interest lies in the effect of the percentage remediated.

Discussion and conclusion

This study quantitatively examines whether students participated in the remediation process, and whether involvement in the remediation process improved students' performance. Following from Handley, Price, and Millar (2011), feedback is irrelevant if no students engage with it. In our study, on average, 70% of students who could remediate a quiz used the opportunity to do so. While this participation rate is high, it raises questions regarding why the remaining 30% of students chose not to participate despite being incentivised to do so. A limitation of the study is that the researchers did not seek students' opinions on the remediation process, their reasons for (not) participating in it, and how the remediation process relates to their learning goals. Students' initial quiz marks clearly impacted their likelihood to remediate. We believe students with higher initial marks were more likely to remediate as less effort would be involved (owing to less significant errors being made initially).

In the light of this, we considered whether remediation could be scaled based on the initial quiz grade but rejected this. First, it would increase the tutors' workload. Also, a sliding scale may cause feelings of unfairness among students, particularly those students who are more conscientious. Alternatively, the opportunity to remediate could only be offered to students who achieved two marks or less on a quiz. However, the current form achieved a balance between the time and effort required by teaching assistants and the potential academic benefit for students.

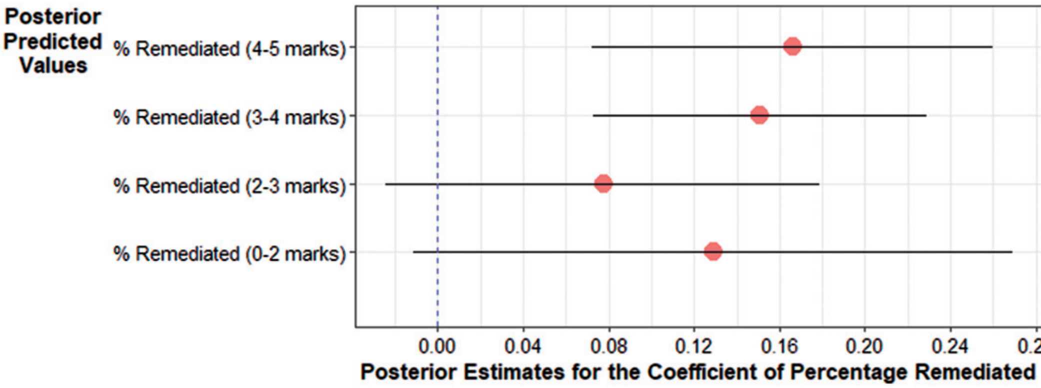

Figure 3. Model Output: posterior estimates of the explanatory variable percentage remediated per group with a 95% credibility interval.

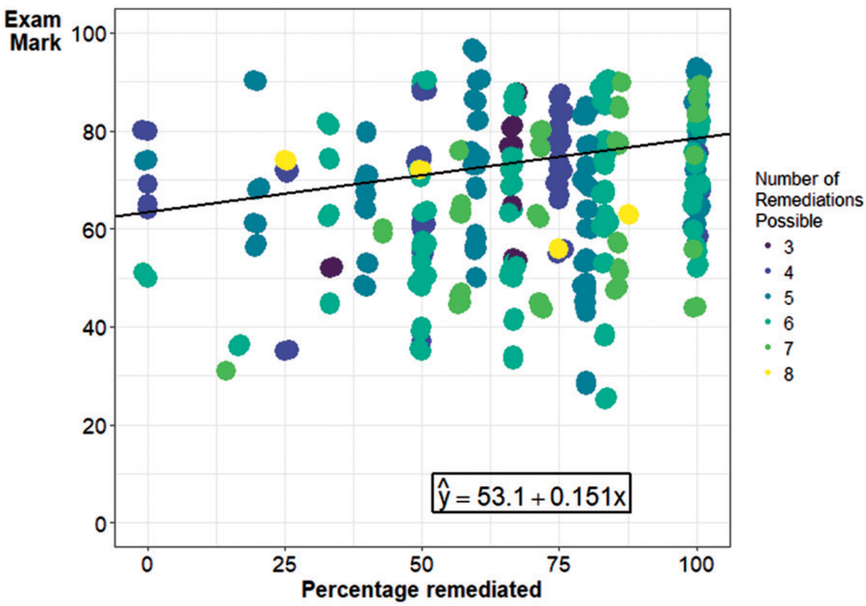

Figure 4. For students who achieved on average a quiz mark in the range of (3,4], the plot gives their percentage remediated versus their final examination mark. The intercept is calculated using the mean mathematics points score and relevant parameter estimates of the intercept and coefficients.

In psychology (Sharpe 2013) and education (López et al. 2015), and indeed throughout the social sciences, Bayesian approaches are rare compared to classical approaches, including hypothesis testing, in analysing data. However, we believe this study shows the strength and flexibility in Bayesian methods. Future studies, using the remediation process or similar, could integrate the posterior information provided within this study to inform their priors.

This study supports Shute's (2008) identification of prior achievement and a student's level as important elements in the effectiveness of formative feedback. By considering each range of student achievement (0–2 marks, 2–3 marks, 3–4 marks and 4–5 marks), we can examine the interaction between participation in the remediation process and student achievement level. Interestingly, the estimated coefficients of the percentage remediated from the Bayesian hierarchical model are more uncertain for low-achieving students. The remediation process may not have aided students in the two lower groups.

Price, Handley, and Millar (2011) assert that students may need help to act on feedback. Low-achieving students were encouraged by their lecturer to seek individual support from the Maths

Table 2. Beta coefficients for the hierarchical model broken down by the factor levels.

	Posterior mean	Posterior std.	2.5%	97.5%
β_1 – percentage remediated				
Average quiz mark				
0–2 marks	0.130	0.073	0.015	0.271
2–3 marks	0.078	0.052	-0.023	0.180
3–4 marks	0.151	0.038	0.077	0.227
4–5 marks	0.166	0.048	0.071	0.260
β_2 – Mathematics points				
Average quiz mark				
0–2 marks	0.756	0.153	0.459	1.051
2–3 marks	0.568	0.118	0.339	0.648
3–4 marks	0.678	0.102	0.477	0.747
4–5 marks	0.353	0.147	0.068	0.452

Note: β_1 and β_2 gives the coefficient values for the numeric explanatory variables percentage remediated and leaving certificate mathematics points, respectively.

Support Centres with their remediations; however, few did. We hypothesise that low-achieving students lacked the level of module content understanding which was essential for the remediation process to be of benefit. Comparatively, the largest group of students (3–4 marks) had this basic understanding. Students in the 4–5 mark group had very few possible remediations and these often involved correcting a calculation 'slip'. Considering this, we believe the remediation process did not improve their understanding, but rather has identified the students who were more likely to engage with all available module resources.

Feedback resources provided to students varied in level of support and detail. The Blackboard data shows that students accessed the quiz solutions within 1 week of receiving their corrected quiz for the eight remediated quizzes only. While we cannot claim that this revision of resources has a long-term effect on students' learning, it is encouraging that students can be incentivised to access module resources. Future research could pursue the relationship between the feedback type(s) accessed or the time feedback was accessed (immediate versus delayed) and the initial quiz mark received (factors considered by Trenholm, Alcock, and Robinson 2015).

Future work will explore how the remediation process can be altered in order to better provide improved support to the low-achieving students. Further qualitative research will analyse the quiz remediations submitted, in order to investigate how students remediated, including whether students took a three-step approach of identifying, describing and correcting their error(s). In our study, we examine remediation in a mathematics/STEM domain. From the Covic and Jones (2008) and Fisher, Cavanagh, and Bowles (2011) studies, we are aware elements of the remediation process, including incentivising students to engage with feedback, are transferable to other subject-domains. In summary, participation in the remediation process supported the majority of students in *Maths for Business*.

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Disclosure statement

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