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Research Article

Exploring the use and impact of online digital resources in a mathematics module

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ABSTRACT

This study examines the relationship between student engagement with digital resources and final module grade in a particular mathematics module delivered online in an Irish technological university. Measures of student engagement with the module are defined and calculated using data from virtual learning environment. These measures are analyzed to provide a description of students' online study habits. We make an initial distinction between resources provided by the lecturer that are *lecture-based* or *exam-focused*. We further categorize student engagement with these resources as *active* or *passive* and consider these measures of student engagement in an online context. With these categories and measures in mind, we then examine the correlation between student engagement and final module grade using a multivariable linear regression model.

Keywords: active student engagement, passive student engagement, mathematics module, digital resources, linear model, student performance

INTRODUCTION

Mathematics plays a key role across multiple disciplines in Munster Technological University (MTU) in Ireland, with a large percentage of students on all campuses in MTU seeing mathematics over the course of their study.

Over the past number of years, the department of mathematics in MTU has engaged in several teaching and learning related projects. Given the nature of service teaching of the department, these projects tend to be multidisciplinary with respect to both staff and students. In 2020/2021 a team of staff in the department working on a project called SPIRIT Maths (students' perceptions informing and redefining teaching in mathematics) developed a large range of digital resources for both business and engineering modules. The development of these resources was informed by a survey of all first-year students who undertake a mathematics or statistics module. To pilot these resources, a mandatory mathematics module, MATH6051

(essential mathematics for business), taken by many first-year students in the faculty of business and humanities, was selected. SPIRIT Maths resources, together with other digital resources that were developed by the module lecturing team, were made available to students taking this module in September 2021, using the university's virtual learning environment (VLE), Canvas.

The rollout of the digital resources developed for this project coincided with a fully online delivery for all modules, including mathematics modules, at the university due to the COVID-19 restrictions in place during the 2021/2022 academic year. Consequently, students had to engage with the MATH6051 module resources online through Canvas and the team could record that engagement using Canvas Analytics data.

Using a multivariable linear regression model, we examine the relationships between measures of student engagement and their impact on a student's module grade. We focus on whether active engagement methods and exam-focused resources are associated with a higher final module grade.

BACKGROUND

Impact of COVID-19 Pandemic on Higher Education

Student engagement is recognized as a very important factor in higher education and there is ample evidence of its role in students' achievement and performances (Carini et al., 2006; Dixson, 2015; Lee, 2014). However, it is also multi-faceted and can be difficult to define and measure (Dixson, 2015; Henrie et al., 2015; Reschly & Christenson, 2012). The study by Dixson (2015) describes student engagement as 'the extent to which students actively engage by thinking, talking, and interacting with the content of a course, the other students in the course, and the instructor'. This broad description encompasses behavioral (effort and perseverance in learning), emotional (affective aspects and sense of belonging) and cognitive (e.g., learning strategies) components of engagement.

Prior to the COVID-19 pandemic, numerous studies investigated student engagement online (Henrie et al., 2015; Hew, 2015; Holmes, 2018; Jacobs, 2013; Kahn et al., 2017; Keengwe & Kidd, 2010; Kim & Bonk, 2006; Lee, 2014; Matias & Wolf, 2013; Paulsen & McCormick, 2020; Wallace, 2003). The study by Lee (2014) found that both behavioral engagement and emotional engagement significantly enhanced performance in learners. Using the knowledge that many students are "assessment driven", it has been found that low stakes weekly continuous e-assessments can significantly increase student engagement and virtual learning activity (Holmes, 2018). Furthermore, exam-focused materials have been found to be a favored resource of students (Cross et al., 2016; Lishchynska et al., 2022).

In the past few decades both students and staff had anticipated an increased move toward online and blended learning. In 2006, for example, a survey (Kim & Bonk, 2006), conducted among 562 college instructors and administrators in the USA, explored their expectations regarding the future roles of online and blended learning. The survey participants predicted a significant increase in the use of course management systems, video streaming, online testing, and exam tools for future online education.

Hew (2015) found that students appreciated active learning strategies, such as projects and games, which were directly tied to the course content. They also found that effective use of course resources, particularly video lectures, was essential and features like bite-sized videos, clear and simple language, multiple perspectives from different lecturers, and downloadable content were highlighted as particularly beneficial for student engagement.

The sudden outbreak of COVID-19 had major and pervasive effects worldwide. As higher education pivoted to online teaching and assessment, online learning, remote access, and e-collaboration were used to an unprecedented extent. Amid this crisis, however, some of the limitations of online learning came to the fore; it did not facilitate contact between the learner and the teacher. Learners also faced technical challenges that hindered and slowed down the process of teaching and learning (Favale et al., 2020). Many countries faced problems in online education in terms of the significant gap between those students from privileged and disadvantaged backgrounds. While some schools and governments have been providing digital equipment to students in need, many are still concerned that the pandemic will widen the digital divide (Li & Lalani, 2020).

With the rise of online learning, student engagement in online learning has become a central issue for researchers and scholars. Certain universities found that the level of engagement in online learning varied significantly across different disciplines (Dembereldorj, 2021). In the higher education sector, institutions focused on high relevance, effective delivery, adequate support, high quality participation and contingency plans to ensure student learning and safety (Bao, 2020). For academic staff during the pandemic, designing and producing effective videos, and improving their digital communications skills for technology enhanced teaching have been identified as key suggestions for better engagement with learners (Chiu, 2020). Tools like Breakout Rooms, Google Chat, Google Meet, Jamboard, Mentimeter, and various VLEs played a significant role in ensuring active student support (Ahshan, 2021). Course satisfaction is one thing that is known to significantly correlate with student engagement. It is significantly related to students' skills, engagement, emotional engagement, participation engagement and performance engagement (Baloran et al., 2021).

Measuring Student Engagement Online

Numerous studies have examined online student engagement, both in the context of online/blended delivery (Argyriou et al., 2022; Cocea & Weibelzahl, 2011; Dixson, 2015; Giesbers et al., 2014; Lang, 2022; Morris et al., 2005; Rajabalee et al., 2020; Stewart et al., 2011) and fully in-person delivery (Boulton et al., 2018). These studies incorporate measures of engagement ranging from data available through a VLE such as completion of online quizzes (Argyriou et al., 2022; Dixson, 2015) daily activity time in a module (Boulton et al., 2018), frequency and hours of access (Lang, 2022), number of contributions to video conferences or online discussion forums (Dixson, 2015; Giesbers et al., 2014), as well as number of assignments completed, importance level of such assignments and activities requiring VLE presence (Rajabalee et al., 2020) to self-reporting instruments (Dixson, 2015).

A review article by Henrie et al. (2015) included 113 studies across a range of educational levels and course deliveries. Three main measures of online student engagement were identified: quantitative self-report measures, qualitative measures, and quantitative observational measures. *Quantitative self-report measures* such as surveys including responses to Likert-scale questions were the most frequent measures of online engagement, used in 61.1% of studies reviewed. *Qualitative measures* obtained through interviews, open-ended survey questions, discourse analysis, or observation measured the quality of engagement and were used in 39.4% of studies. *Quantitative observational measures* such as time spent on VLE, time spent on a task, frequency of logins and the number of web pages or files viewed were measured in 34.5% of studies. The remaining 11.5% of studies reviewed used other measures of engagement such as biometric data.

The focus of this paper is on quantitative observational measures of student engagement through VLE. Henrie et al. (2015) note that the main strengths of these measures include the ability to capture student activity, the abundance of data and that the gathering of data does not disrupt student learning. These measures capture aspects of the behavioral component of student engagement but do not directly capture the emotional and cognitive aspects. It is possible that some emotional and cognitive aspects of student engagement are correlated with the measures of behavioral engagement as indicated in the study by Dixson (2015). Student self-reports of engagement (measuring emotional, cognitive, and behavioral aspects of engagement) were found to correlate with quantitative observational measures from VLE. Vogt (2016) also investigated the correlation between engagement as measured by frequency of VLE activity and students' own perceived levels of engagement as measured by a student engagement questionnaire but found no correlation. It is also worth noting that Vogt's (2016) study relates to campus-based students' online engagement as opposed to the study presented in this paper, which concerns students in a fully remote setting.

Measures of Online Student Engagement & Academic Performance

Studies exploring the relationship between quantitative observational measures of student engagement captured through VLE and academic performance report a positive association for some measures (Argyriou et al., 2022; Lang, 2022; Morris et al., 2005; Rajabalee et al., 2020). Morris et al. (2005) examined the relationship between several engagement measures from VLE and final grades using data from three asynchronous online undergraduate courses. Out of the measures of engagement analyzed, it was found that the number of discussion posts viewed, the number of content pages viewed, and seconds viewing discussion

posts were positively associated with the final grade achieved. In a blended learning setting, Argyriou et al. (2022) found that higher completion rates of weekly online quizzes predicted final exam performance for an undergraduate psychology course. A case study by Lang (2022) explored the relationship between many engagement measures obtained through VLE and the final grade for a fully online course with a live component. The study identified that the number of hours that the student was active on VLE, the number of times that the 'lecture materials' were accessed and the number of times that a student attempted the formative quizzes were positively correlated with final grade.

Scope of Current Paper

It has been noted in the literature review that within the framework of technological interventions, it is the effect of technology on student engagement that is often examined, with 'a dearth of studies in undergraduate mathematics education that specifically focus on student engagement with technology' (Ní Shé et al., 2023). It is precisely that engagement with technology that is the focus of the current paper. In this paper, our interest is primarily in student engagement with the technological resources, and the impact of this engagement on student learning and success, as opposed to the impact of the technology on student engagement. Thus, in this paper we are less concerned with student engagement in its broadest sense, but with student engagement with certain technological resources available to students in MTU for a particular mathematics module. The measures of such engagement fall into the category of the quantitative observation measures discussed before, derived from log data of students' interactions with VLE.

Many of the quantitative observational measures examined by Henrie et al. (2015) do not provide a measure of the quality of engagement (Appleton et al., 2008; Dixson, 2015) and this is certainly true for measures such as time spent on VLE, frequency of logins and the number of web pages or files viewed. For the purposes of this paper, we distinguish between *passive* and *active engagement.* We note that, while there are numerous articles on active learning (Braun et al., 2018; Gavalcová, 2008; Pengelley, 2020; Prince, 2004), where the accepted meaning of this term relates to classroom-based learning strategies, our focus is on learning resources that are either supplementary or alternatives to face-to-face classes and are accessed principally in the students' own time. We therefore use the term *active engagement* to refer to the use of resources, where the student has demonstrably engaged with the resource beyond accessing the resource in the first place; in our context this engagement is used to reflect participation such as selecting an answer to a multiple-choice question or entering a numerical or algebraic answer. It should be noted that, for us, the correctness of an input answer was not essential to be counted as an instance of active engagement. We will refer to the use of the other types of resources as *passive engagement*.

By passive engagement we mean the accessing of the digital resources (lecture videos and notes, past exam question videos, exercises, and past exam questions–in either PDF or Numbas[1] format), where there is no observable engagement with the resource outside of simply accessing it in the first instance. We emphasize that this is not meant to imply that such use of resources is necessarily passive or even suboptimal but only that there is no way of assessing the extent of engagement with the resource.

Irish Context

Leaving certificate, often referred to as leaving cert, is the standardized examination taken by students in the Irish secondary school system when leaving school. Points, known as leaving cert points (or CAO points), are allocated based on the student's performance in Irish, English and mathematics together with three other subjects. Students can choose to do either a higher or ordinary level in each subject, which impacts on the number of points awarded for each subject, as shown in **Table 1**.

In addition, 25 bonus points are awarded for a grade H6 and above in higher level mathematics. This is intended to encourage students to take higher level mathematics in leaving cert. However, for MATH6051 module, which is the focus of this study, only 36 out of 231 students took higher level mathematics.

The points obtained in leaving cert examinations are used in conjunction with specific course entry requirements to determine a student's eligibility for various higher education programs. Each program has a minimum points requirement, and students compete for available places based on their leaving cert points.

[1] Numbas is an open access online assessment system developed at Newcastle University (Perfect, 2015).

Table 1. Relationship between leaving cert grades & leaving cert points

Higher level	Points	Ordinary level	Points
H1 (90.0%-100%)	100	O1 (90.0%-100%)	56
H2 (80.0%<90.0%)	88	O2 (80.0%<90.0%)	46
H3 (70.0%<80.0%)	77	O3 (70.0%<80.0%)	37
H4 (60.0%<70.0%)	66	O4 (60.0%<70.0%)	28
H5 (50.0%<60.0%)	56	O5 (50.0%<60.0%)	20
H6 (40.0%<50.0%)	46	O6 (40.0%<50.0%)	12
H7 (30.0%<40.0%)	37	O7 (30.0%<40.0%)	0
H8 (0.0%<30.0%)	0	O8 (0.0%<30.0%)	0

Moreover, it is known (Higher Education Authority, 2019) that leaving cert points scored in English and mathematics are a good predictor of student retention and future academic success in third level education. We will therefore use the points scored for mathematics in leaving cert ('leaving cert maths points') as a variable for our model.

In Ireland, as well as eight traditional universities, there are five technological universities (TUs), including MTU. TUs were formed in 2019 through mergers of existing institutes of technology. TUs and the predecessor institutes have been, and still are largely, mainly focused on teaching, with both academic staff and students having a high number of weekly contact hours although, increasingly research is becoming a major part of academic duties.

Description of MATH6051 Digital Resources

The module MATH6051, essential mathematics for business, usually has an annual enrolment of over 200 students. There are typically six class groups of 40-50 students each for the purposes of delivering this module, and several lecturers are assigned to separate deliveries of the module, with close cooperation between them. Notably, all students of MATH6051 have the same final examination paper (worth 60.0% of the module mark), Excel lab examinations (worth 20.0%), and computer-based continuous assessments, using the Numbas platform (worth 20.0% in total, between three or four assessments).

Before the pandemic, the following resources were typically provided by the module lecturers and made available on Canvas:

(1) exercise sheets,

(2) answers to exercise sheets,

(3) lab sheets (for use during Excel labs),

(4) notes on the various module topics, and

(5) past examination papers (with answers).

These resources were in PDF or Word format. The next subsections will describe the additional resources that were developed in Semester 1, 2020.

Lecture based digital resources

For the online delivery of this module, in Semester 1, 2021, two lectures were posted in the form of interactive booklets for each teaching week of the semester, giving a total of 22 lectures for the semester. These interactive booklets were developed using H5P, a platform for creating interactive digital content. A typical lecture would consist of five sections, each containing a short video (usually four-six minutes in length) and a set of accompanying exercises. These exercises were embedded at the end of each of the lecture videos, with the aim of testing students' knowledge of the material covered in that video. Students could type in their answers for the exercises and receive immediate feedback on the correctness of their answers. At the end of each lecture, students received a score based on how well they performed on the exercises. While these scores did not affect the student's module grade, the scores could be viewed by the lecturing team. The scores also provided additional motivation for students to engage with the lecture materials. In addition to the interactive video/exercise content, each lecture had an accompanying set of written notes presented in PDF format. To provide additional opportunities for students to practice, eight exercise sheets were also made

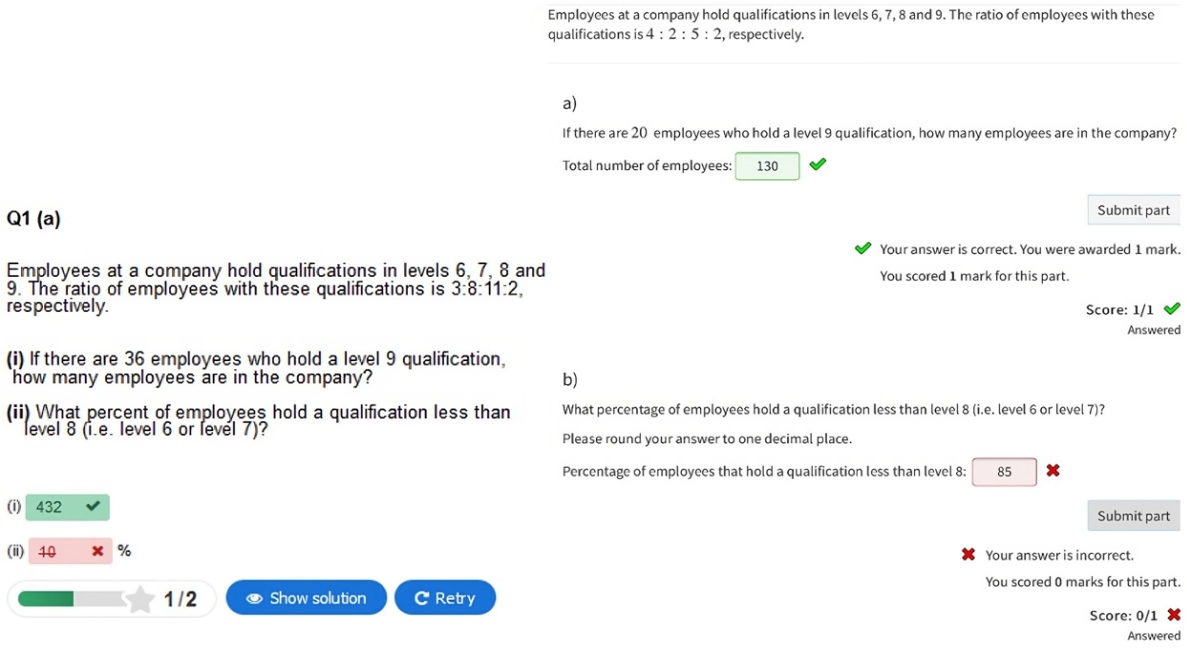

Figure 1. Screenshots of an H5P self-assessment question & a Numbas practice question (Source: Authors)

available. These resources were made available on the MATH6051 home page on Canvas, with the respective lecturers also giving some live classes with their groups through Zoom.

SPIRIT Maths exam-focused resources

As part of SPIRIT Maths project, a survey was carried out to establish students' preferences for digital resources (Lishchynska et al., 2022). Having noted these preferences and drawing on the experience of the lecturers involved in the project, three interlinked sets of resources were developed: self-assessment questions (either identical to past exam questions or differing only in the numbers used in the question), videos showing full solutions to exam-style questions and a bank of further practice questions.

The self-assessment questions were created using H5P, while the banks of practice questions were created using Numbas (see **Figure 1**). The idea was that a student accessing the resources via Canvas would attempt a question on a given topic, check if their answer was correct, and then view a recorded solution of a very similar question, if desired. The student could then attempt other similar questions on Numbas, and avail of features such as checking their answer, receiving feedback if one of several common errors was detected, viewing the full solution, and regenerating the question to attempt another of the same style but with different parameters. These resources were developed for three different exam-style questions, using the three questions that appeared on the Winter 2019 exam paper as a template. SPIRIT Maths resources for MATH6051 were uploaded to a designated page within the module's section on Canvas, and the availability of the resources was communicated to students of this module through the announcements feature on Canvas with a link to the resources included in the announcement. This was done at the end of the fourth week of the semester, just after the students' first assessment and immediately preceding the reading week in MTU when there are no lectures. Initial announcement was reinforced by further reminders in Canvas announcements, as well as by announcements in lectures, and emails to class groups. A more comprehensive description of SPIRIT Maths survey and resources are in Lishchynska et al. (2023) and Palmer et al. (2022), respectively.

Aims of Case Study

In subsequent sections of the paper, we describe how user data from Canvas has been used to quantify student engagement, explore patterns of student engagement, and examine the relationship between measured engagement and module grade. The measures of student engagement are summarized with the aid of descriptive statistics and a linear regression model is applied to investigate the degree to which engagement with the resources was associated with improved student performance as measured by the module grade. The work has four main aims:

1. Define and calculate several student engagement metrics using data from VLE.
2. Describe the online study habits of students enrolled in the module.
3. Examine the correlation between various measures of student engagement.
4. Examine the associations between engagement measures and module grade with a focus on two specific research questions:
   a. Are active engagement methods associated with higher grades?
   b. Are exam-focused resources associated with higher grades?

In summary, our work is characterized by the following features:

(1) it is concerned with measuring student engagement,

(2) the engagement measured relates to digital resources,

(3) these digital resources are supplementary to classroom activities, which are the primary focus of the module lecturers,

(4) we distinguish between active and passive use of the digital resources, and between exam-focused and non-exam-focused resources,

(5) the study relates to the time during the global pandemic when emergency remote teaching (ERT) was used, and

(6) we are concerned exclusively with a particular mathematics module, which is taught to many business students in first year in MTU.

METHODOLOGY

Measuring Student Engagement with Digital Resources

The module resources were primarily distributed using three of Canvas's features: *pages*, *files,* and *assignments*. A Canvas page is a composite object, which can include text, videos, and links to other module content. The materials for each of the 22 lectures and 3 SPIRIT Maths past paper questions were hosted on their own page. The written lecture notes and exercise sheets were uploaded as PDF documents through the files feature on Canvas. The assignments feature on Canvas allows users to submit graded work. SPIRIT Maths Numbas practice questions were set up as assignments to allow access to data on the percentage grade[2] received from student submissions. For each student enrolled in a module, Canvas analytics provides an Access Report, which contains information on student interactions with the module resources. It was possible to collate this information in the form of a CSV file for all students enrolled on MATH6051 using a Python script (see O'Sullivan, 2021). The resulting data set contained information on the number of times each student accessed each Canvas page, file, and assignment. Using this, it was possible to determine the number of times a student accessed each lecture page, set of lecture notes, exercise sheet, SPIRIT Maths past paper page and SPIRIT Maths Numbas exercise. Access report also included the amount of time the student spent logged on to the MATH6051 module on Canvas.

H5P software, which was used to deliver the lecture content has a built-in analytics system, which provided access to data on which students made submissions as well as the percentage grade obtained for these submissions. In addition to these measures of student engagement, the final module grade, and leaving cert Points[3] for mathematics were also recorded for each student. These serve as measures of student performance and prior learning, respectively. It should be noted that in this study, the grade for the Excel component of the module was excluded from the analysis, as the digital resources examined did not pertain to that portion of the module. Therefore, when we refer to *module grade*, we consider only the students' scores in the continuous assessments and final exam. Any results quoted exclude the mark the student achieved in the Excel component. A summary of the different variables that were recorded for each student is presented in **Table 2**.

[2] This grade had no bearing on the final module grade.
[3] The Leaving Cert points were obtained from the students' records.

Table 2. A summary of different measures of engagement that were recorded for each student

Variable name	Variable description	Min, Q1, median, Q3, & max
Lectures accessed	Number of lecture pages, which were accessed at least once.	0, 5, 12, 20, & 22
Lectures submitted	Number of lectures for which a H5P submission was made.	0, 0, 2, 5, & 22
Total lecture views	Total number of views across all lecture pages, accounting for multiple views of same lecture.	0, 12, 33, 58, & 403
Written notes accessed	Number of PDF lecture notes, which were accessed at least once.	0, 0, 1, 3, & 26
Exercise sheets accessed	Number of exercise sheets, which were accessed at least once.	0, 0, 2, 4, & 8
SPIRIT Maths Numbas accessed	Number of SPIRIT Maths Numbas exercises, which were accessed at least once.	0, 0, 0, 2, & 17
SPIRIT Maths Numbas submitted	Number of SPIRIT Maths Numbas exercises for which a submission was made.	0, 0, 0, 0, & 17
SPIRIT Maths videos accessed	Number of exam paper questions for which a video of worked solutions was accessed at least once.	0, 0, 0, 0, & 3
Exam questions practiced	Number of exam paper questions for which either a video of worked solutions was accessed or a Numbas exercise was submitted (or both).	0, 0, 0, 0, & 3
Total time on VLE	Total number of hours student spent logged into MATH6051 module on Canvas.	0, 3.9, 8.5, 17.1, & 586.5
Leaving cert maths points	Points obtained in students leaving certificate mathematics exam.	0, 20, 28, 41.5, & 100
Module grade	Percentage grade student obtained for MATH6051 module, excluding Excel component.	0, 33.1, 47.3, 61.7, & 100

Note. Variables that measure use of lecture-based resources are shaded in blue, variables that measure use of exam-based resources are shaded in green, & variables that require active student engagement are shaded in a darker color

The measures *lectures accessed* and *lectures submitted* described in **Table 2** capture different levels of engagement with the lecture resources. A student is recorded as having accessed a lecture page if they open the page on their web browser; there is no guarantee that the lecture video will be watched. In contrast, if a student is recorded as having submitted answers to a H5P exercise for that lecture then they have demonstrably actively engaged with the material. Similarly, the measures *SPIRIT Maths Numbas accessed* and *SPIRIT Maths Numbas submitted* (**Table 2**) capture different levels of engagement with the exam-focused resources. A student is recorded as having accessed a Numbas question if they open the page on their web browser, but they are only recorded as submitting a question if they input an answer. Differences in these measures of accessing materials vs actively engaging with them will provide information on student behavior for online learning and the reliability of using measures of webpage activity as a proxy for engagement.

The variable *exam questions practiced* were not measured directly from Canvas analytics. It combines information from the variables *SPIRIT Maths videos accessed* and *SPIRIT Maths Numbas submitted* to capture the extent to which a student engaged with the exam-focused materials. This was necessary due to the low numbers of students engaging with the exam-focused materials. Aggregating the two variables provided a meaningful measure of engagement with the exam-focused resources that could be included in the linear regression model.

Data Analysis

Statistical analyses were performed using R 4.1.2 for Windows (R Core Team, 2021). Descriptive statistics were used to describe student engagement with the variables listed in **Table 2**. The distributions of the variables are summarized graphically using histograms and density plots or summarized in the text using frequencies and percentages. Medians and interquartile ranges are provided in **Table 2**. The consistency of different measures of student engagement with the digital resources was assessed using Spearman rank correlation.

For the statistical modelling, the outcome variable was *module grade*. A multivariable linear regression model was selected to explore the relationships between *module grade* and the following pre-specified variables: *leaving cert maths points*, *lectures accessed*, *lectures submitted*, and *exam questions practiced*. The variable *leaving cert maths points* was included to account for the effect of prior learning on mathematical performance in third level (Alyahyan & Dustegor, 2020; Faulkner et al., 2014; Higher Education Authority,

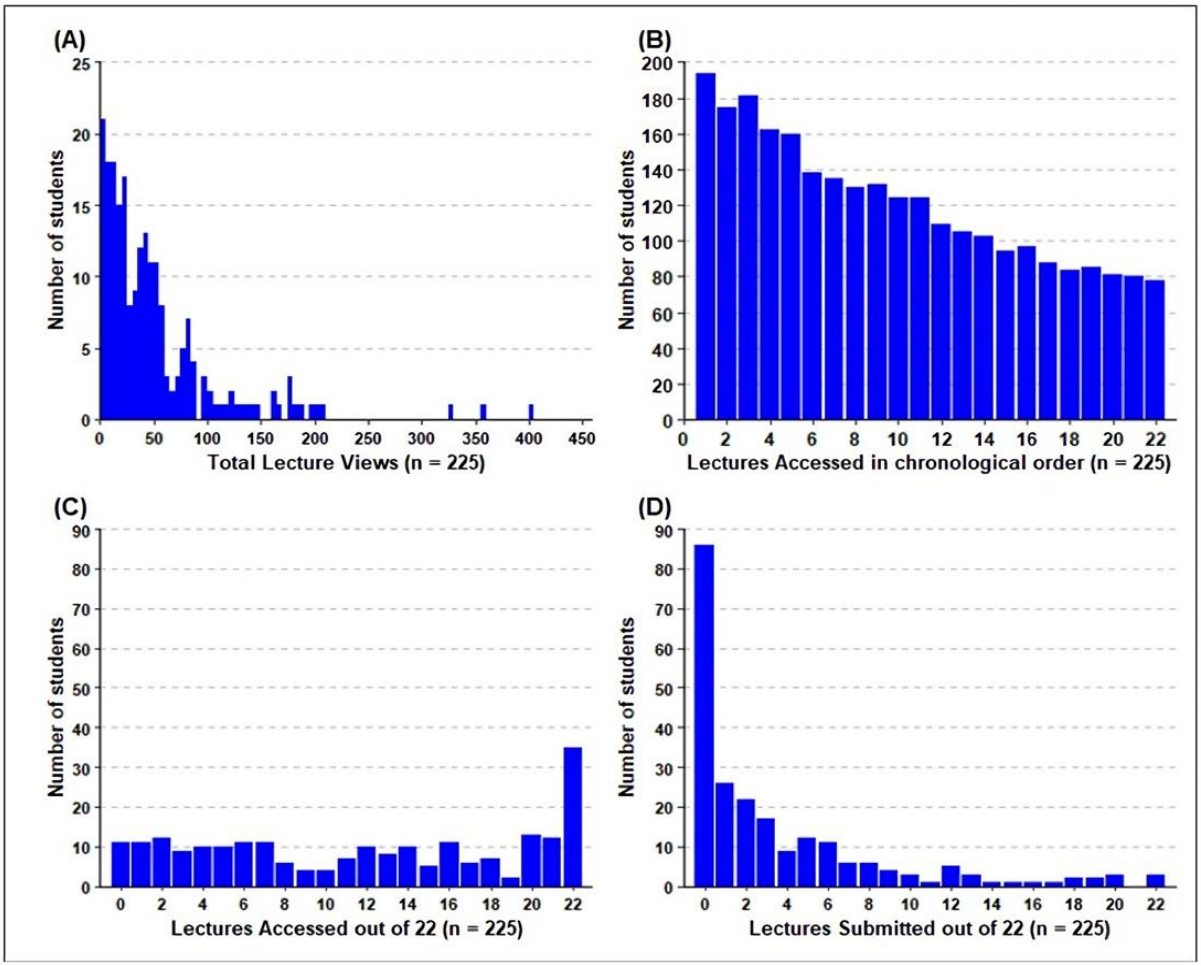

Figure 2. Distributions-1: (A) Distribution of total number of views across all lecture pages accounting for multiple views of same lecture; (B) distribution of lectures accessed in chronological order (one corresponds to first lecture & 22 corresponds to last lecture); (C) distribution of number of lecture pages, which were accessed at least once; & (D) distribution of number of lectures for which a H5P submission was made (Source: Authors)

2019). The variables *lectures accessed,* and *lectures submitted* were included to examine the research question: *Are active engagement methods associated with higher grades?* The variable *exam questions practiced* were included to examine the research question: *Are exam-focused resources associated with higher grades?* The continuous variables *leaving cert maths points*, *lectures accessed*, *lectures submitted* were normalized before fitting the model to allow comparisons of the regression coefficients. The full set of parameter estimates, associated confidence intervals and p-values for the fitted model are reported. Diagnostic plots of the residuals indicated that the assumptions of linearity, homogeneity of variance and normality of the standardized residuals were satisfied for the fitted model. No influential points were identified. Collinearity between the explanatory variables was checked using Pearson's correlation coefficient and variance inflation factors for the model were below 1.5.

RESULTS

Use of Lecture-Based Resources

Lecture pages containing videos and H5P questions were the most frequently accessed resource with 214 (95.0%) out of the 225 students accessing the lecture pages at least once.

Part A in **Figure 2** shows the distribution of lecture page views; it shows that most students accessed the lecture pages between one and 50 times. Since there were a total of 22 lecture pages, this indicates that in

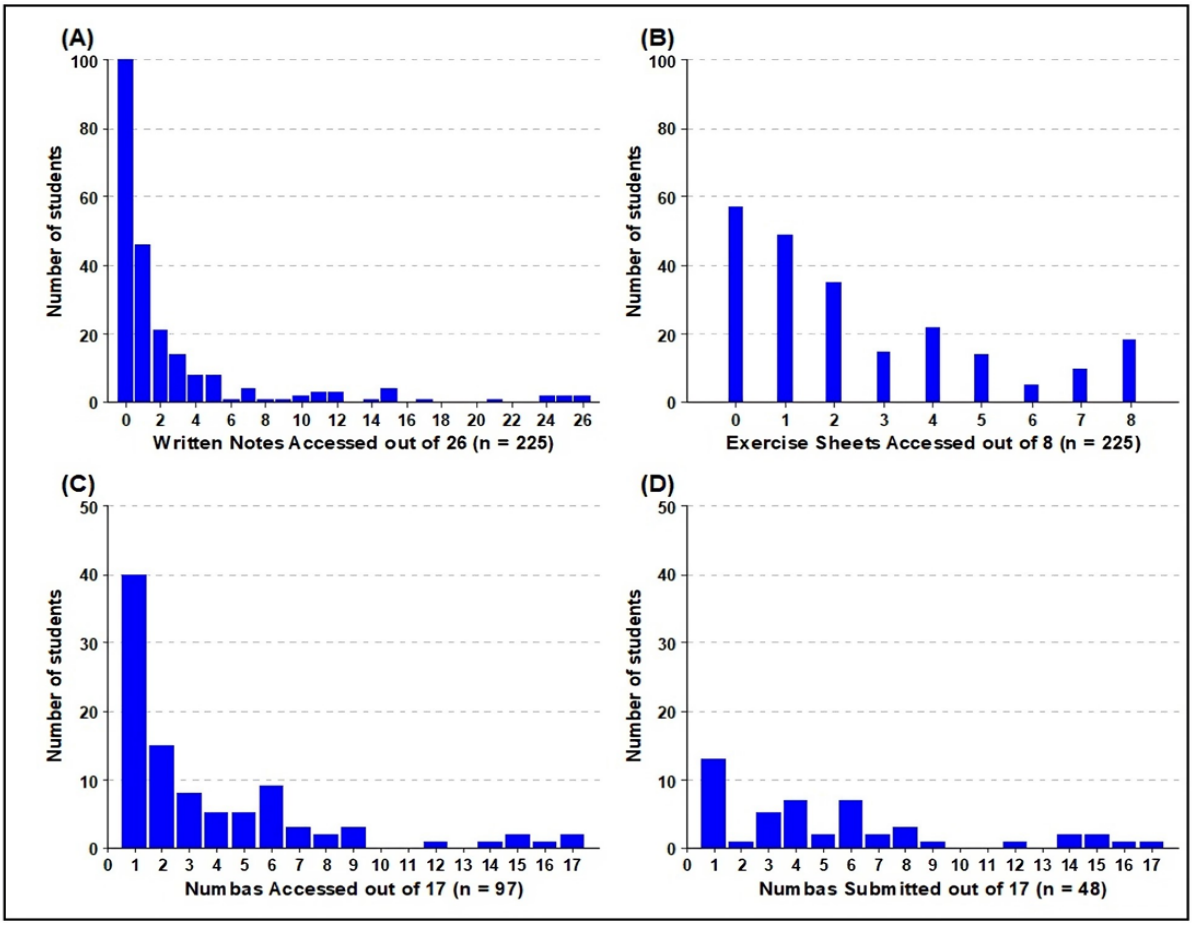

Figure 3. Distributions-2: (A) Distribution of number of PDF lecture notes, which were accessed at least once; (B) distribution of number exercise sheets, which were accessed at least once; (C) distribution of number of SPIRIT Maths Numbas exercises, which were accessed at least once; & (D) distribution of number of SPIRIT Maths Numbas exercises for which a submission was made (Source: Authors)

general, students accessed each lecture no more than twice with some students not accessing the complete set of lectures.

This is highlighted in part B in **Figure 2**, which shows that the number of students accessing the lecture pages decreased over the semester. At the start of the semester, 194 students (86.0%) accessed the first lecture, which decreased to 78 students (35.0%) accessing the final lecture by the end of the semester; less than half the number who accessed the first lecture. There are three notable outliers in part A in **Figure 2**; these students accessed the lectures over 300 times. Although these numbers seem high, the highest recorded value of 403 equates to approximately 18 views per lecture page, which, although unlikely, is not impossible. One possible explanation is that the webpage was refreshed numerous times, possibly due to connection issues or leaving tabs open. Part C in **Figure 2** shows the number of lectures accessed by each student; this gives a measure of engagement that is not affected by connectivity issues or browsing habits but does not account for multiple views of the same lecture page. A total of 35 students (16.0%) accessed all 22 lectures but many students skipped some of the lectures. Indeed 106 students (47.0%) skipped at least half of the lectures. Part D in **Figure 2** shows the number of H5P questions submitted by each student; this gives a measure of active engagement with the resources. Just three students (1.0%) completed all 22 H5P practice questions and 86 students (38.0%) did not attempt any. Comparing part C in **Figure 2** to part D in **Figure 2** shows fewer students actively engaged with resources in comparison to those simply accessing resources.

The other lecture-based resources were PDFs of lecture notes and exercise sheets. Part A in **Figure 3** shows the number of PDF notes (out of 26 PDFs) that each student accessed. We see that 100 students (44.0%) did not use the written notes at all and relied solely on the lecture videos. Part B in **Figure 3** shows the number of exercise sheets (out of eight) that each student accessed. The exercise sheets were accessed the least out

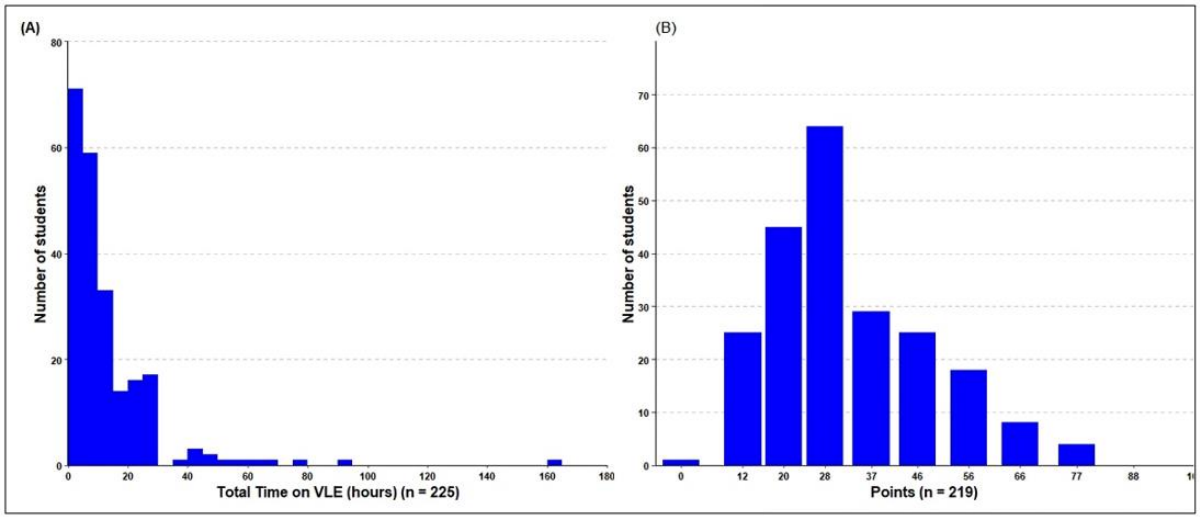

Figure 4. Distributions-3: (A) Distribution of total time spent on VLE; & (B) distribution of leaving cert maths points (Source: Authors)

of the lecture-based resources; 57 students (25.0%) did not access a single exercise sheet to practice questions and 18 students (8.0%) accessed all eight exercise sheets.

Use of SPIRIT Maths Exam-Focused Resources

The exam-focused resources include video solutions to past-paper questions and complementary Numbas questions for further practice. There was a total of 112 students (50.0%) who accessed the exam-focused materials; 42 (19.0%) accessed the videos of solutions to past papers, 97 (43.0%) accessed the Numbas questions (part C in **Figure 3**) and 27 students (12.0%) accessed both. There were three past paper questions with video solutions; 25 students accessed one question, three students accessed two questions, and 14 students accessed three questions.

For Numbas exercises, in addition to access data, submission data was available (i.e., data on whether a student submitted an answer to a question rather than simply accessing the webpage). Part C in **Figure 3** shows the distribution of the total number of Numbas exercises accessed (out of 17) and part D in **Figure 3** shows the distribution of the total number of submissions (out of 17). A total of 48 students (21.0%) submitted answers to Numbas exercises, which is approximately half of the students who accessed the exercises. As was the case for the lectures, fewer students actively engaged with the resources in comparison to those simply accessing the resources.

One of the aims of this study was to examine the impact of exam-focused resources on student grades. Since only a small subset of students actively engaged with the video solutions and Numbas exercises, the variable *exam questions practiced* aggregates the variables *SPIRIT Maths videos accessed* and *SPIRIT Maths Numbas submitted* to provide a measure of the extent to which students engaged with the exam-focused resources. For the variable *exam questions practiced* 154 students (68.0%) did not engage with the exam-focused resources at all, 37 students (16.0%) practiced one question, 11 students (5.0%) practiced two questions and 23 students (10.0%) practiced all three questions.

Total Time Spent on Virtual Learning Environment & Consistency of Measures of Student Engagement

The median time spent on VLE over the semester was 8.5 hours and 143 students (64.0%) spent less than 12 hours in total, averaging less than one hour per week (**Figure 4**). There were two unusually large times recorded of 587 hours and 161 hours, neither of which correspond to the individuals with large values recorded for *total lecture views.* This could indicate that the large values for *total lecture views* may be due to connectivity issues rather than leaving tabs open.

Several measures of student engagement have been presented in this study. To measure the consistency of these different measures, Spearman's rank correlation coefficients were calculated. The three variables

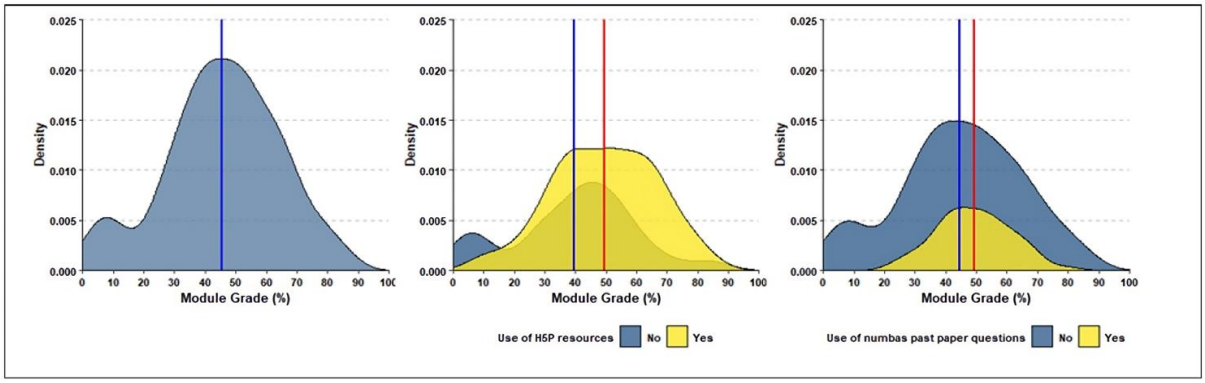

Figure 5. Distributions-4: (A) Distribution of grades for students (mean shown in blue) n=225; (B) distribution of grades for students who did/did not use H5P resources (means shown in red/blue); & (C) distribution of grades for students who did/did not use Numbas resources (means shown in red/blue) (Source: Authors)

that captured the behavior of the most students were *total lecture views*, *lectures accessed* and *total time on VLE*. The analysis showed that the other variables, *lectures submitted*, *written notes accessed*, *exercise sheets accessed*, etc. were only engaged with by a subset of students; therefore, we only calculate correlation between the three main measures of engagement. The highest correlation is between *total lecture views* and *lectures accessed;* this correlation was 0.91 ($p<0.001$) indicating that students with a high number of total lecture views were more likely to access a larger number of lecture resources. The correlation between *total lecture views* and *total time on VLE* was 0.67 ($p<0.001$) and the correlation between *lectures accessed* and *total time on VLE* was 0.72 ($p<0.001$). These correlations with *total time on VLE* were lower, indicating that students with a high number of hours recorded on VLE were not necessarily engaging with the materials more effectively than other students with lower hours recorded.

Module Grades & Prior Learning

To pass the module, a grade of 40.0% or above is required. Out of the 225 students who completed the module, 144 students (64.0%) passed. The overall distribution of grades for the module is shown in part A in **Figure 5** and the impact of active resource use on grades is shown in part B in **Figures 5** (use of H5P resources) and part C in **Figure 5** (Numbas resources). A total of 139 students (62.0%) engaged with the H5P resources (submitted answers to practice exercises). Out of these students 95 (68.0%) passed the module. The grades for students who used the H5P resources were on average higher (49.0%) than those who did not (40.0%); this can be seen in the grouped density plot shown in part B in **Figure 5**.

A total of 48 students (21.0%) submitted answers to the Numbas exam-focused exercises. Out of these students 38 (79.0%) passed the module. The grades for students who used the Numbas exam-focused resources were on average higher (49.0%) than those who did not (45.0%). This can be seen in the grouped density plot shown in part C in **Figure 5**. The distribution of grades for students who used the Numbas exam-focused resources is narrower than the distribution of grades for the students who did not use the resources (part C in **Figure 5**). We see fewer students who used the resources achieved very high or very low grades.

When the exam-focused resources are combined and we consider students who either accessed the videos of solutions to exam questions or submitted answers to Numbas questions, or both, we found that a total of 71 students (32.0%) engaged with the exam-focused resources. Of these, 56 (79.0%) passed the module. The grades for students who used the exam-focused resources were on average higher (51.0%) than those who did not (44.0%).

Focusing on the number of students who attained a pass mark, the breakdown regarding engagement with exam-focused resources can be seen in **Table 3**. We can see that, of the students who passed the module, 39.0% engaged with the resources. On the other hand, of the students who failed the module, only 19.0% had engaged. In the other direction, 79.0% of students who engaged with the resources passed the module. By contrast, 57.0% of students who did not engage with the resources passed the module.

The variable *leaving cert maths points* is included in the linear regression model as a measure of prior learning; the distribution is shown in part B in **Figure 4**. There was a wide range of results slightly skewed

Table 3. Breakdown of students who passed/failed with regard to engagement with exam-focused resources

	Engaged	Did not engage
Students who passed (144)	56	88
Students who failed (81)	15	66
Total (225)	71	154

Table 4. Multivariable linear regression model summary for *mathematics grade* (adjusted R^2=42.3%) (n=219)

Variables	Coefficient estimate	95% CI		p-value
		Lower	Upper	
Leaving cert maths points	8.710	6.758	10.662	<0.001
Lectures accessed	5.489	3.198	7.781	<0.001
Lectures submitted (H5P)	3.005	0.772	5.238	0.009
Exam questions practiced (out of three with zero as reference point)				
1	2.059	-3.221	7.339	0.443
2	0.559	-8.749	9.867	0.906
3	7.530	0.744	14.315	0.030

toward lower results and notably no students achieved points from the highest two categories. There were six missing values for this variable, reducing the sample size to 219.

Associations Between Engagement Measures & Module Grade

The results of the multivariable linear regression model are shown in **Table 4**. The results indicate that there is a positive association between *module grade* and the variable *leaving cert maths points* (95% confidence interval [CI], 6.758-10.662). On average, students with higher points in their leaving certificate mathematics exam achieved a higher grade in their mathematics module. There was also a positive association between *module grade* and *lectures accessed* (95% CI, 3.198-7.781) and *module grade* and *lectures submitted* (95% CI, 0.772-5.238). On average, students who viewed a larger number of lectures and submitted a larger number of H5P practice questions achieved a higher grade in their mathematics module. For the variable *exam questions practiced*, students who practiced all three past paper questions were more likely to achieve a higher grade than students who did not practice any past paper questions, but the data did not provide evidence that students who practiced one or two past paper questions were more likely to achieve a higher grade than students who did not practice any past paper questions. An F-test to examine the overall variation in *module grade* that can be explained by the variable *exam questions practiced* did not find evidence of an association, F(3, 212)=1.646, MSE=341, p=0.178.

DISCUSSION

Our study has explored the use and impact of digital resources developed for a mathematics module, delivered online during the COVID-19 pandemic. We

(1) defined and calculated several different measures of student engagement in an online environment and used Spearman's rank correlation to compare these various metrics for consistency,

(2) used these metrics to describe student engagement with the online module resources, and

(3) examined the relationships between student engagement and final module grade using a multivariable linear regression model to determine whether active engagement methods and exam-focused methods are associated with higher grades.

Measures of Student Engagement & Correlation Between Measures

Many student engagement metrics were considered throughout this study. Extracting user data available from Canvas, the passive engagement variables were identified as *lectures accessed, total lecture views, written notes accessed, exercise sheets accessed, SPIRIT Maths Numbas accessed, SPIRIT Maths videos accessed*, and *total time on VLE.* As against this, the active engagement variables were *lectures submitted*, *SPIRIT Maths Numbas submitted*, and *exam questions practiced.*

Because the number of students who engaged with the exam-focused resources was small, the number of past exam question video solutions accessed and number of exam-style Numbas questions submitted were amalgamated as a measure of engagement with exam-focused resources.

While *total lecture views* and *total time on VLE* correspond to commonly used measures of engagement across much of the literature relating to the measurement of online student engagement (Cocea & Weibelzahl, 2011; Lang, 2022; Tempelaar et al., 2015), we believe that *lectures accessed* is a more appropriate measure of student engagement as it is less sensitive to some common student behaviors that could affect the other two: refreshing a page due to poor internet connectivity would inflate *total lecture views*, whereas having VLE open in a dormant tab would inflate *total time on VLE*. One of the limitations of this metric is that no distinction is made between a student who simply accesses a lecture and exits immediately without engaging with the lecture video and a student who watches the lecture video in full or accesses the same lecture multiple times. However, we believe that it is unlikely that many students would continue the former behavior across all lectures throughout the semester, while internet connectivity issues or the practice of leaving tabs open would likely be consistent across the full semester. Moreover, this point is relevant to the studies of (Dixson, 2015; Henrie et al., 2015) who acknowledge that frequency measures of engagement may reflect the quantity but not necessarily the quality of engagement of a student. Thus, a student who fully engaged with a video once and achieved a full understanding of the content in one viewing cannot necessarily be said to be less engaged than a student who viewed the video multiple times to achieve a similar level of understanding. Choosing *lectures accessed* over *total lecture views* as a measure of engagement helps to avoid the assumption that higher frequency of access implies better quality engagement.

Of the measures of engagement considered, three were found to capture the behavior of most students: *total lecture views*, *lectures accessed*, and *total time on VLE*. The very strong positive correlation between *Total lecture views* and *lectures accessed* suggests that these measures are fundamentally capturing the same information. The weaker correlation between *total time on VLE* and the other two measures indicates that large amounts of time being spent logged into VLE does not necessarily mean that the students are engaging with the available resources. This finding is also expressed in existing research such as (Dixson, 2015; Henrie et al., 2015) who note that evidence of accessing a resource does not give any indication as to the quality of engagement with the resource.

Studies examining the correlation between measures of student engagement have focused on correlation between engagement as measured by frequency of VLE activity and students' own perceived levels of engagement as measured by self-report data (Dixson, 2015; Vogt, 2016). However, there is little information regarding the correlations between quantitative observational variables derived from VLE. One study that goes some way to describing such correlations is that of Macfadyen and Dawson (2010), who use regression modelling to create a predictive model of students' overall grades in an online biology module. However, while the authors note that, of the thirteen initial VLE variables that demonstrated a significant correlation with student grades, three variables were omitted to avoid issues of multi-collinearity, no further detail is given in relation to correlation between individual variables.

Online Study Habits

It is widely accepted that there is a relationship between study habits and academic achievement (Jafari, 2019; Rabia et al., 2017; Sasi & Anju, 2020). Although not every learning strategy or study habit produces useful results in terms of academic achievement, it would be expected that students with good study habits in general are better performers than students with poor study habits (Nonis & Hudson, 2006). In an online context, Lang (2020) examined student activity on VLE over each quarter of the semester and noted that '*students who adopted a steady approach with consistent levels of activity through the semester achieved higher scores than those who procrastinated*'.

We saw that the resources most frequently accessed by the students were the lecture videos and H5P questions. This reflects a strong preference by students for resources made by their lecturer, as noted by (Morari & O'Rourke, 2022) in MTU context. This is also consistent with other studies, such as Dewhurst et al. (2010). Also, over time, the number of students watching the videos did drop with fewer students watching the final lectures: as illustrated in part B in **Figure 2** there is quite a steady decline in the number of students accessing the lecture videos with just over half of students accessing the final lecture video compared to the

first. This phenomenon has also been observed in studies such as Boulton et al. (2019) and Van Blerkom (1992).

In contrast, many students (around 44.0%) did not access the written notes and one in four did not access the exercise sheets at all. Even more surprising was the fact that only 19.0% of students looked at video solutions to the past papers. Given the preference for exam-based or assessment driven materials expressed by students in numerous studies (Adanir et al., 2020; Cross et al., 2016; Lishchynska et al., 2022), the team expected this number to be significantly higher In particular, a study by (Cross et al., 2016), students were asked to rate the usefulness of several exam revision resources, including sample exam answers, tutor advice/support and feedback from assignments. Sample exam answers were perceived to be the most useful resource by a considerable margin. Overall, it seems that while many students accessed the lecture videos, a significant proportion did not engage with the complementary materials provided. However, those who did use the exam-focused resources tended to perform better and have higher grades, suggesting that these resources could be beneficial for students.

The challenge therefore becomes one of improving the levels of engagement with these complementary resources. Demonstrating the use of these resources in class time, directing students to specific resources when finishing a topic or assigning a low-stakes grade for participation with the resources are some possible approaches. Supports may also need to be put in place for students who do not have ready access to the required technologies–laptops, tablets, adequate internet connections etc.–the lack of which (Hollister et al., 2022) highlights as a significant barrier to learning for some students.

Associations Between Student Engagement & Module Grade

Students' prior knowledge and understanding of mathematics, and their degree of comfort with it is known to influence their subsequent level of success and retention in higher education institutions. Although the focus of this study was to explore the relationships between measures of online student engagement and module grade, it was necessary to account for the effect of prior knowledge on module grade. As expected, and in line with other studies (Derr et al., 2018; Faulkner et al., 2014; Higher Education Authority, 2019; Lishchynska et al., 2022), prior achievement is seen to be strongly associated with final module grades in this study.

In the broad context of measures of online engagement in relation to module grades, our findings are consistent with those of (Argyriou et al., 2022; Boulton et al., 2018; Lang, 2022; Morris et al., 2005; Rajabalee et al., 2020), where aspects of VLE usage are shown to be associated with academic achievement in an online context. However, it is important to note that a variety of measures were examined across the different studies and this detail is important. For example, our study supports the findings by Lang (2022) who found that the number of hours that the student was active on VLE the number of times that the 'Lecture Materials' were accessed and the number of times that a student attempted the formative quizzes were positively correlated with final grade. The study conducted by Argyriou et al. (2022) discovered no link between the rate of asynchronous video views and final exam scores, which contrasts with the findings of this study. However, both studies agreed on the positive correlation between online quiz completion rate/H5P completion rate and module grade. In the research conducted by Boulton et al. (2018), they examined numerous modules in a face-to-face setting. Student engagement was measured as the average daily VLE activity per module. Their findings indicated that there's a positive correlation between active participation in VLE and achieving higher grades in modules. Interestingly, they observed that low activity on VLE did not consistently lead to lower grades. They note that it is difficult to predict final module grades from VLE activity alone due to the predominance of other "offline" learning activities. However, in the situation we consider, which was characterized by ERT, VLE had become a practically indispensable aspect of the learning environment, so any such offline learning activities were probably much less significant for students included in this study.

Are active engagement methods associated with higher grades?

The use of passive engagement measures such as those noted above is unsatisfactory as a sole measure of engagement, as it is difficult to state with any confidence to what level a student who clicked on a page truly engaged with the content. Dixson (2015) acknowledges the limitations of what she terms '*observational learning behaviors*'–students recorded as reading or viewing content–as a proxy for true engagement for the

same reason. By contrast, students who submitted answers to either H5P or Numbas questions can be said to have demonstrated at least some explicit engagement with the resources.

The results from our linear regression model show that active engagement is associated with higher overall module grade. This result is consistent with other studies such as Argyriou et al. (2022) who found that higher completion of weekly online quizzes was a predictor of performance on the final exam. Similar observations were also reported by Lang (2022), where the number of times students attempted quizzes was shown to have a positive correlation with the students' overall marks.

Is engagement with exam-focused resources associated with a higher module grade?

The mean module mark for students who used the exam-focused resources was 7.0% higher than those who did not, indicating that engagement with exam-focused resources is beneficial for student performance. Students who practiced all three past paper questions were more likely to achieve higher grades than those who did not practice any past paper questions. This observation is consistent with Lang (2022), where engagement with formative quizzes (designed to prepare students for the end-of-semester exam) was found to be strongly positively correlated with overall grade. It also agrees with Cross et al. (2016), who found that sample papers were a useful exam revision resource. They noted that studying sample papers can increase a student's familiarity with exam question style and format, something that could not be achieved from studying lecture notes or other resources.

Limitations

We acknowledge that our study relates to a particular cohort of students in a particular academic year. We also note the difficulty of confidently establishing conclusions of a causal nature, since there are liable to be confounding variables. One may argue that what is measured in this study under the heading of 'engagement' is not wholly consistent with any accepted definition of engagement. Nevertheless, we argue that it is closely related to engagement, it is an objective measure that does not suffer from the vagaries of self-reported or third-party observed manifestations of engagement, and it suggests practical interventions and types of digital resources that may be useful to students in similar educational circumstances.

We have restricted attention to measuring student engagement through VLE with a particular focus on interactions with digital resources. This does not capture the full extent of student engagement as described by Dixson (2015); in particular, it does not account for peer-to-peer interactions or student-lecturer interactions, which have been shown to be an important factor for student learning and retention (Broadbent & Poon, 2015; Smith et al., 2011; Trowler, 2010). Furthermore, this study considers only behavioral engagement, defined in Fredricks and McColskey (2012) as engagement through participation such as time on task etc. and referred to as academic engagement in Appleton et al. (2006). However, emotional, and cognitive engagement–a student's reactions and feelings towards their environment, peers and teachers, and the value a student places in learning, respectively (Fredricks & McColskey, 2012)–have also been found, in some studies, to contribute to students' learning (Appleton et al., 2006; Carini et al., 2006; Lee, 2014). The inclusion of measures of emotional and cognitive engagement in this study could provide a richer insight into the students' overall engagement. Several student engagement questionnaires have already been developed and validated, including student course engagement questionnaire (Handelsman et al., 2005), student engagement instrument (Appleton et al., 2006) and online student engagement scale (Dixson, 2015). Using instruments such as these, as well as focus groups, the broader engagement of students who engaged well with the resources discussed in this study, as well as those who did not, could be compared against exam performance, with the overall findings then compared to the results presented here and those of previous studies.

CONCLUSIONS

While measuring student engagement in an online, digitally mediated context is the subject of several articles (Dixson, 2015; Henrie et al., 2015; Lang, 2022), satisfactory measures of student engagement are difficult to establish. We have focused on data that can be obtained directly from VLE based on the individual students' usage of the resources made available by the lecturer. We have distinguished in this work between

exam-focused and lecture-focused resources on the one hand, and active and passive engagement on the other.

When analyzing the correlation between various measures of student engagement, we concluded that *lectures accessed* captures essentially the same information as *total lecture views*, but without the artificial inflation inherent in *total lecture views* that arises from refreshing the lecture page because of poor internet connectivity. Exaggeratedly high numbers associated with *total time on VLE* because of dormant tabs are similarly mitigated by using *lectures accessed* as a measure of engagement.

The results of our regression model show that the number of lectures accessed, and the number of submissions made are both associated with higher grades. In this study, the number of students who engaged with the exam-focused resources was quite low. Nonetheless, the results point to an improvement in grades for those students who engaged fully with these resources. A natural challenge is how to encourage students to avail themselves of all the resources that are available to them.

Obstacles that deter effective engagement with digital resources such as technological constraints, accessibility issues, and motivational factors are also of interest, in particular their role in the digital divide and their impact on student engagement and academic performance.

In addition, while the current research is centered around a mathematics module taken by business students, it would be interesting to know how this might vary across different academic disciplines. Exploring the variance in digital resource engagement across several fields would enhance our understanding of disciplinary differences in digital education strategies. One additional further consideration for future research is whether repeat students use resources such as those examined in this study differently to students attempting the module for the first time. Gaining an insight into the specific study habits of repeat students could be helpful in providing targeted resources for this cohort of students, some of whom–due to timetabling challenges or other reasons–may have difficulty in attending classes in person.

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Data availability: Data generated or analyzed during this study are available from the authors on request.

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