CASE STUDY

Digital Resources for Targeted Mathematics Support

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Abstract

SPIRIT Maths (Students' Perceptions Informing and Redefining Innovative Teaching of Mathematics in Higher Education) is a project that was established in Munster Technological University (MTU) to investigate students' attitudes towards mathematics and to explore a more student-centred development of mathematics resources. One of the aims of the project was to create a collection of student-preferred digital materials with a view to improving student engagement, building students' confidence in mathematics and helping students to succeed in their mathematics modules.

The findings of a survey disseminated to first year students in MTU indicated that students would be most likely to use the resources if they were geared towards their specific module; to maximise impact, resources were developed for two modules, one in Engineering and one in Business, that are each taken by large numbers of students. The resources were integrated on the learning management system and are available to all MTU students taking a mathematics module. Three interlinked digital resources were developed: (1) a series of interactive self-assessment questions, (2) corresponding videos showing worked solutions and (3) an associated bank of practice questions developed using a digital tutor to provide instant feedback. It is hoped that the complementary resources will facilitate student learning through a combination of active learning, explicit instruction and the ready availability of the resources.

This article describes these resources and how they were developed, and outlines how these are being promoted to students. We also report on the feedback received from a small number of students who tested the resources and discuss how to measure student engagement with the resources.

Keywords: digital resources, mathematics and statistics support, student perspective, learning technology, online mathematics support.

1. Introduction

Munster Technological University, one of Ireland's newest Higher Education Institutions, was established on the 1st January 2021 from a merger of Cork Institute of Technology and Institute of Technology Tralee. The Department of Mathematics in MTU is primarily a service department and plays a key role in almost every programme in MTU. Out of 3,169 first year students in the academic year 2020/2021, 2,260 (71.3%) took at least one mathematics or statistics module. While mathematics is clearly a fundamental aspect of many programmes, it is often perceived as difficult and can present an obstacle to students from other disciplines. For example, up to 40% of first year students on some programmes failed a mathematics module at their first attempt. To address this, the SPIRIT Maths project sought students' insights and preferences in relation to their study of mathematics and created resources based on these findings.

As part of the SPIRIT Maths project, two surveys (for students who enrolled pre and post COVID-19) were disseminated to over 1,600 first year MTU students in June 2020 and February 2021. These surveys invited students to share their experiences, perceptions and attitudes towards mathematics. Comparison of the results from the two instances of the survey revealed no statistically significant differences, so the responses from the two surveys were combined. Any references to survey results for the remainder of this paper therefore refer to results from the combined data. When participants were asked to rate a selection of resources to help them to master their mathematics modules, "Videos on past exam papers", "Digital tutor" (software allowing students to practise mathematics questions and receive feedback) and "Videos showing worked solutions to exercise sheets" were each rated as 5 (most effective) by 33.3%, 42.3% and 49.5% of respondents respectively (n = 312, 309, 309 where n refers to the number of respondents who ranked each of the given resources). Furthermore, when asked to rate the usefulness of specific digital resources (as one of "Not useful", "Somewhat useful" and "Very useful"), 72.9% of respondents rated an online bank of practice questions specific to their mathematics modules as "Very useful", while 51.8% of respondents rated a web portal with searchable topics and links to online resources such as text material and videos as "Very useful". The findings of the survey informed the development of the digital resources which we describe below. For further details on the SPIRIT Maths survey, see Lishchynska et al. (2022).

The remainder of this paper is structured into five sections. In Section 2 we present the design objectives and features of the resources, in Section 3 we discuss how the resources are integrated into the online learning environment at MTU, in Section 4 we report student feedback following resource testing and in Section 5 we consider how to monitor student engagement with the resources and discuss the main points to consider for future resource development.

2. SPIRIT Maths Resources

2.1. Design Objectives and Implementation

Informed by the results of the SPIRIT Maths student survey, and the resource developers' teaching experience, the SPIRIT Maths resources were designed to satisfy four key requirements: the resources should: (1) be time efficient from the student's perspective, (2) be tailored to the student cohort, (3) facilitate active learning and (4) be easy for the student to navigate and access relevant materials. Considering these requirements, three interlinked digital resources were developed: a series of interactive self-assessment questions, corresponding videos showing worked solutions and an associated bank of practice questions (see Figure 1). The three interlinked resources were developed for two first year mathematics modules at MTU, one delivered on a business programme and the other on an engineering programme. Both modules are taught to a large number of students (approximately 500 students combined), and both modules suffer from high failure rates. The resources were piloted by a small group of student volunteers and the feedback gathered was used to further improve the resources. We discuss the features of each resource and their implementation below and highlight how, together, they satisfy the four design objectives.

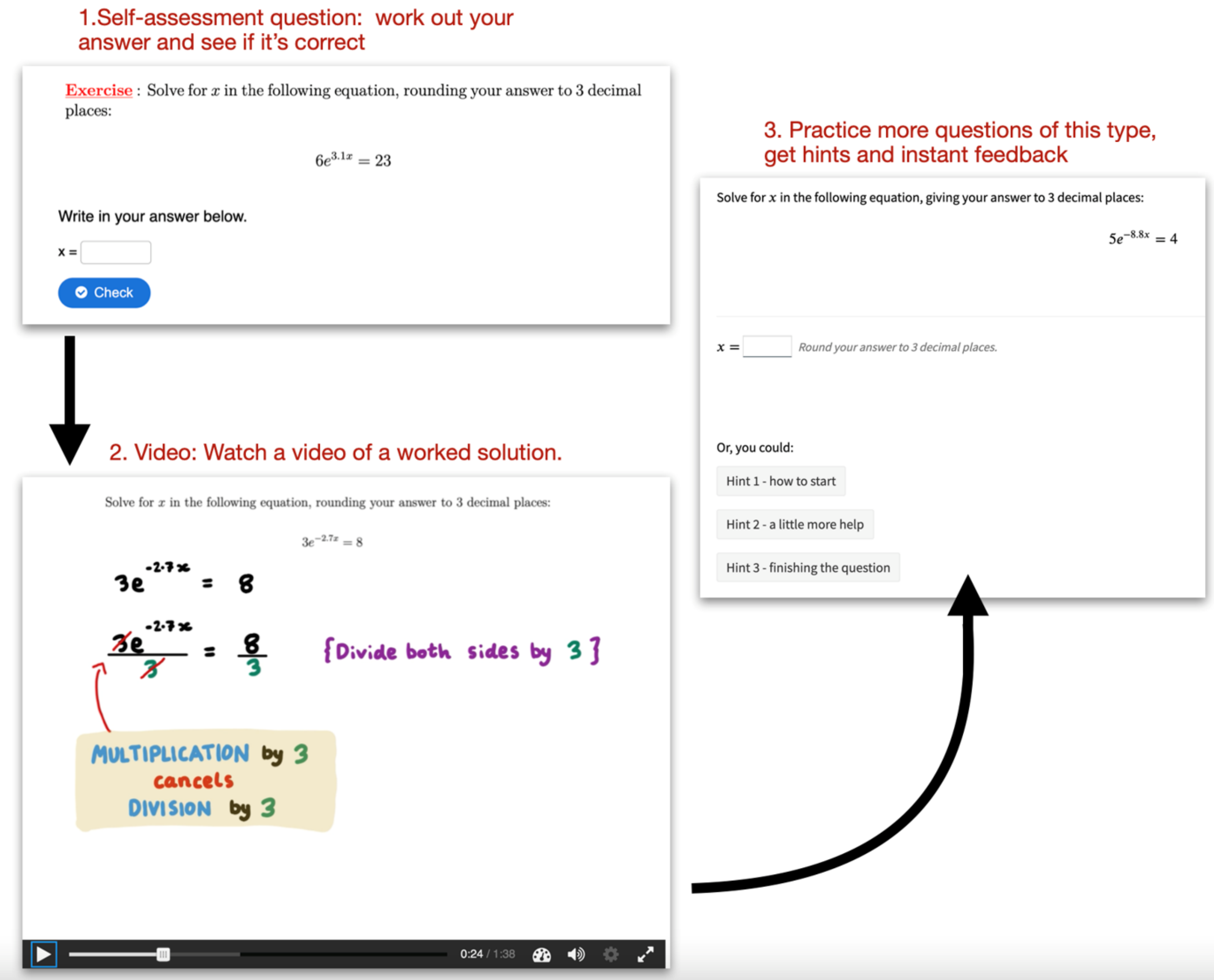


Figure 1. An example of the three interlinked digital resources to support student learning.

2.2. H5P self-test questions

H5P is a software tool which can be used to create interactive web content. It integrates easily with most of the common learning management systems, including Canvas, the system used in MTU. H5P was used to write an initial self-test question based on exercise sheets or past exam papers where the student can test their existing knowledge. The "Fill in the Blanks" content option allows the user to enter their answer, which can then be verified by clicking the "Check" button. Reports of submitted answers are available to the lecturer; monitoring these can provide valuable feedback showing where exactly the students are going wrong (see Figure 2). If the student correctly solves the question and is comfortable with the content, they can then focus on other topics that they are less comfortable with. As well as the benefits associated with time management, the H5P self-test questions also engage the user with the material from the start; students are required to actively solve a problem rather than absorb information passively. The benefits of active learning are widely acknowledged (Prince, 2004; Freeman, et al., 2014), and in addition to this, an incorrect answer provides strong motivation to focus on the accompanying video.

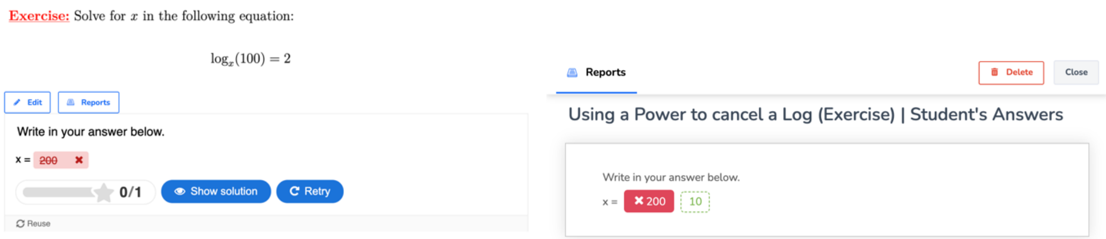


Figure 2. An example of one of the H5P self-test questions (left) and the lecturer's view of the submitted response (right).

2.3. Videos

Each H5P self-test question is followed by a video providing explicit instruction on how to answer the question. In a study analysing 6.9 million video-watching sessions (of which 2.8 million were related to a statistics course), Guo, Kim and Rubin (2014) found that "video length was by far the most significant indicator of engagement" with recorded video content, and recommend videos of less than 6 minutes in length to maximise student engagement. The use of shorter videos to increase the likelihood of viewers watching the full video in a single sitting was also recommended by Nielsen (2020), following analysis of the use of video recordings in a flipped classroom course in engineering mathematics. Videos created in the SPIRIT Maths project were therefore kept short with most of them shorter than 5 minutes, and focused only on the key problem-solving steps, with a view to facilitating both engagement and time efficiency.

There are numerous short videos freely available online covering a wide range of topics in mathematics. Two popular examples include Khan Academy (Khan, 2022) and the videos from "3Blue1Brown" (Sanderson, 2022). However, rather than providing links to existing videos, lecturers created their own videos from scratch. The advantages of this are threefold; (1) videos can be tailored to course specific content; (2) according to the student survey, materials provided by the module lecturer were the most frequently used resources during remote delivery (Lishchynska, et al., 2022); (3) there is evidence that instructor generated videos can improve student learning (Hegeman, 2015). Lecturers creating the videos were given discretion in terms of the style of production, with some videos taking the format of a full-screen video showing the solution being handwritten by the lecturer, accompanied by a narrated explanation while others were designed as silent animated videos in which all problem-solving steps were written on screen. Students had an option to adjust the playback speed to a slower pace if they needed more time to process the steps.

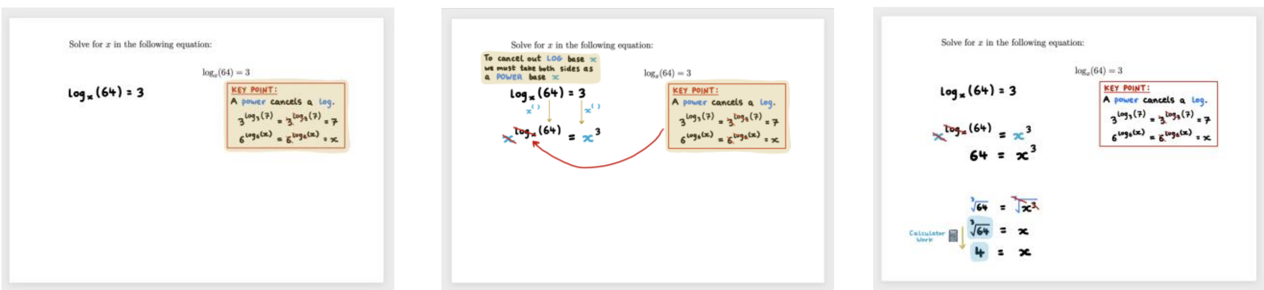


Figure 3. Images from one of the short, animated videos.

2.4. Numbas questions

Accompanying each H5P question and worked video solution is a bank of Numbas practice questions, accessed via a link below or beside the video. Numbas is an e-assessment tool that provides users with instant feedback and allows for a variety of question formats. Each Numbas question was created to match the corresponding H5P question and video solution, with the same wording, but with randomly generated numbers that change each time the question is generated.

The questions are structured to allow students to work at their own pace with a series of supports available depending on individual need. Students are initially invited to try the question themselves and enter their answer. If their answer is correct, they have the option of trying further questions by selecting “Try another question like this one” at the end of the question. If their answer is incorrect, or if they are unsure how to start the question, students can select “Reveal answers” to see a full solution to the question before trying a new question of the same type. For some questions, as well as the full solution, students have the option of selecting one or more hints to help guide them through the question (see Figure 4). After each hint, students can continue with the question themselves or request a further hint. Both the hints and full solution emulate the corresponding worked video solution.

Question progress: Solve for x → *Hint 1 - how to start*

Solve for x in the following equation, giving your answer to 3 decimal places:

$$6e^{-0.6x} = 5$$

Beginning with the given equation:

$$6e^{-0.6x} = 5,$$

we first divide both sides by 6 - the number in front of the exponential term - so that the exponential term will then be on its own:

$$\frac{6e^{-0.6x}}{6} = \frac{5}{6} \qquad \{\text{Divide both sides by } 6\}$$

DIVISION by 6
cancels
MULTIPLICATION by 6

$$e^{-0.6x} = \frac{5}{6}$$

Can you now use the key point from the worked example video to continue on with the question? To continue the question by yourself, click "Go back to the previous part" below or click "Solve for x" in the question progress bar at the top of the question. Otherwise, if you need some more help, click "Hint 2 - a little more help" below for a further hint.

What do you want to do next?

Go back to the previous part

Hint 2 - a little more help

Hint 3 - finishing the question

Figure 4. Students can access step-by-step hints to help guide them through the question.

In addition to providing worked solutions and hints, Numbas can also be set up to provide feedback to address misconceptions and catch common errors. If a student enters an incorrect answer that indicates the answer was arrived at due to a particular misconception, then specific feedback can be provided, explaining why the answer is incorrect and how to obtain the correct answer (see Figure 5).

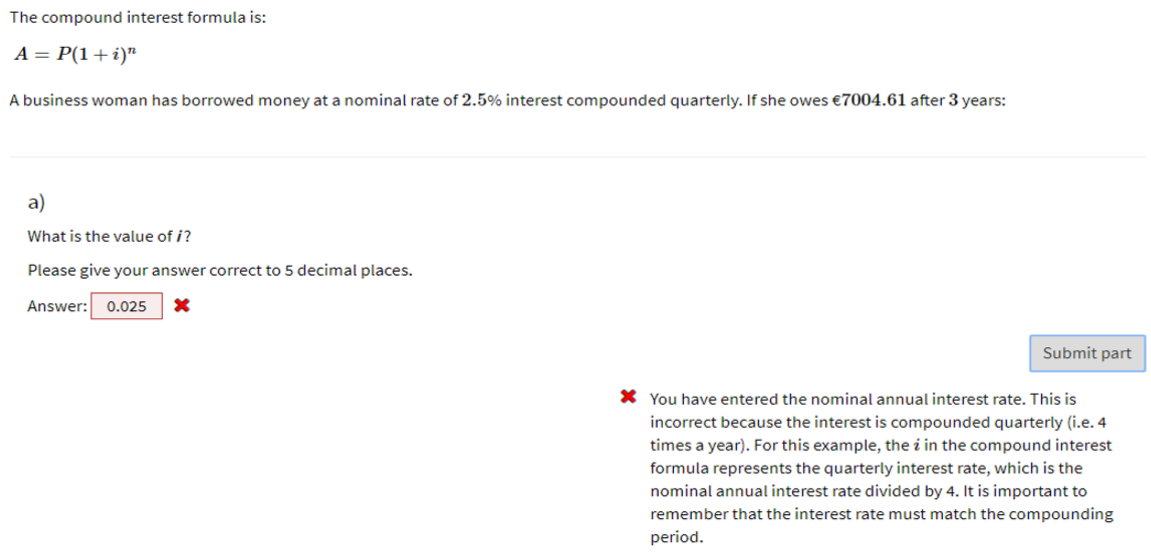


Figure 5. Specific feedback is provided to address common misconceptions.

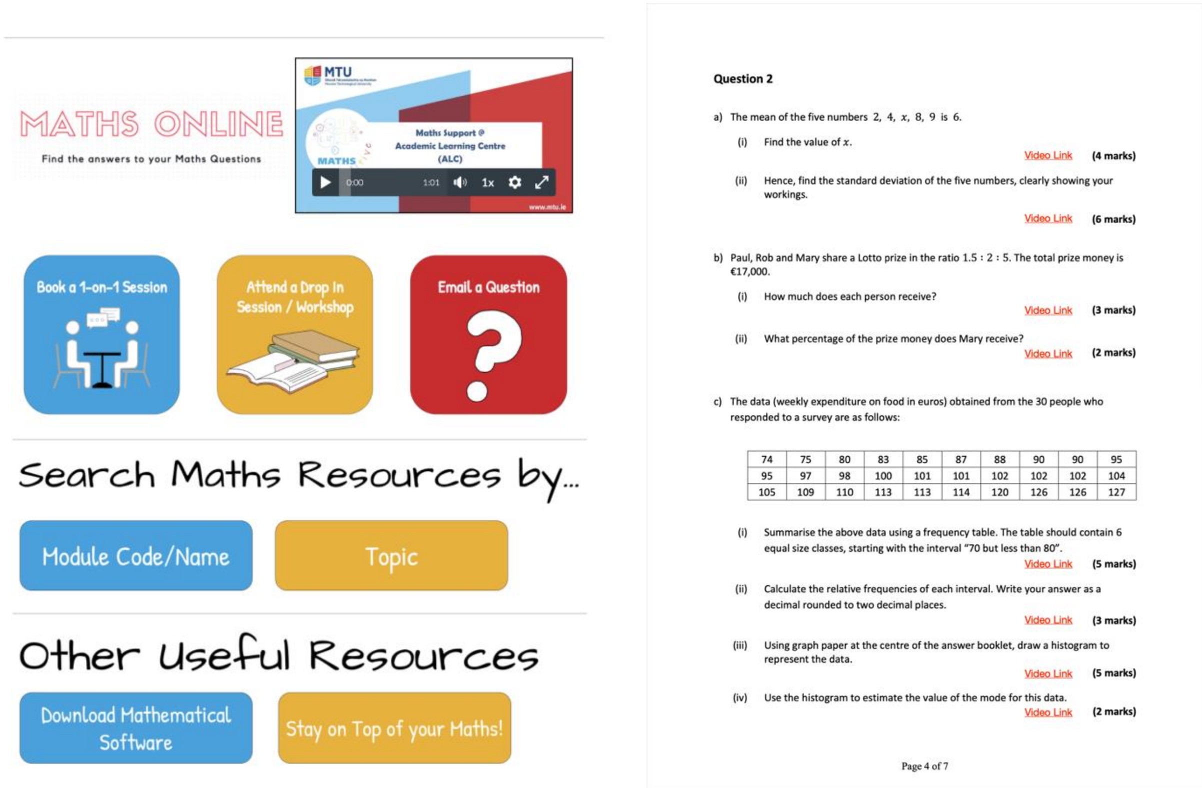
The inclusion of practice Numbas questions facilitates student learning through: (1) formative feedback which enables students to gauge their own understanding of the material, (2) explicit instruction in the form of step-by-step solutions, (3) scaffolding by breaking down questions into parts with optional hints, (4) catching common misconceptions by providing specific feedback for common incorrect answers and (5) encouraging flexible thinking by providing students with problems that seem different on the surface but have the same underlying structure.

2.5. H5P or Numbas?

The initial self-assessment questions were developed using H5P while the banks of practice questions were created using Numbas. Both systems serve a similar purpose in the project – providing an interactive platform for students to test their knowledge of mathematical concepts. When initially developing the resources, the team was keen to utilise individual resource developers' own knowledge and familiarity with specific tools, in order to maximise the potential of the systems used and also to avoid the additional investment of time associated with learning a new system. As the project evolved, various differences between the two systems emerged. Questions developed using both H5P and Numbas are easily embedded into a page on learning management systems such as Canvas, with little difference in terms of presentation or usability. However, Numbas proved significantly more flexible in terms of the types of student response that could be accepted as well as offering a wider range of question styles, including the option of randomising variables if required and providing customised feedback. On the other hand, H5P does not have as steep a learning curve as Numbas and H5P questions have a slightly more attractive interface when embedded into a page. The specific types of question and answer required and whether the option to provide multiple questions using different randomised variables is desired might therefore inform a potential resource developer's choice of system.

3. Online learning at MTU

The SPIRIT Maths resources are integrated within Canvas via "Maths Online", a specialised Canvas module developed by the mathematics support centre in MTU. This module serves as a hub for all things maths support related; students can book one-to-one help sessions with lecturers, attend topic specific workshops and access a wealth of additional maths materials. All students taking a mathematics module are automatically enrolled in the Maths Online module; in 2020/2021 approximately 3,500 students were enrolled. The resources on Maths Online are organised by module code/name, allowing students to quickly identify exactly which materials are relevant to them. The SPIRIT Maths resources are hosted within this existing structure, making the materials readily accessible to students. In addition to being able to access the resources by searching for a topic within their module, students can also access the resources through embedded links within the pdf files of past exam papers. By accessing a single pdf file, the student therefore has the solutions available at their fingertips if needed. Whether they need the guidance of the full video or just want to check their answers, all the student needs to do is click the link next to the part of the question they are working on (see Figure 6).



Question 2

a) The mean of the five numbers $2,\ 4,\ x,\ 8,\ 9$ is 6.

(i) Find the value of x.
Video Link (4 marks)

(ii) Hence, find the standard deviation of the five numbers, clearly showing your workings.
Video Link (6 marks)

b) Paul, Rob and Mary share a Lotto prize in the ratio $1.5 : 2 : 5$. The total prize money is €17,000.

(i) How much does each person receive?
Video Link (3 marks)

(ii) What percentage of the prize money does Mary receive?
Video Link (2 marks)

c) The data (weekly expenditure on food in euros) obtained from the 30 people who responded to a survey are as follows:

74	75	80	83	85	87	88	90	90	95
95	97	98	100	101	101	102	102	102	104
105	109	110	113	113	114	120	126	126	127

(i) Summarise the above data using a frequency table. The table should contain 6 equal size classes, starting with the interval "70 but less than 80".
Video Link (5 marks)

(ii) Calculate the relative frequencies of each interval. Write your answer as a decimal rounded to two decimal places.
Video Link (3 marks)

(iii) Using graph paper at the centre of the answer booklet, draw a histogram to represent the data.
Video Link (5 marks)

(iv) Use the histogram to estimate the value of the mode for this data.
Video Link (2 marks)

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Figure 6. Students can access the resources by searching under Module Code/Name or Topic or by clicking on video links embedded in past exam papers.

4. Feedback

The first version of the resources was piloted by five volunteer students in semester two of the 2020/2021 academic year and feedback was gathered via an online survey and short follow up interview. Following initial feedback, the resources were updated and additional feedback was gathered from a further five students over the summer. The second round of feedback was a slightly longer survey that included additional questions regarding alternative layouts for the resources. All volunteers were asked to spend 1-2 hours testing the resources and were compensated for their time.

The surveys contained both qualitative and quantitative information. The quantitative information has been summarised directly and the main themes emerging from the qualitative data have been summarised following the guidance of Wellington (2000). The general response to the resources was very positive with an overall rating of 4.3 out of 5 (with a score of 5 being the most useful). The videos were identified as being the most useful resource with an overall rating of 4.6 out of 5. The clear explanations provided by the videos, the ability to rewatch solutions, to control the pace of learning and have immediate access to a solution were identified as the most useful aspects of the videos. Other positive aspects of the resources in general included: linking to similar practice questions in Numbas, instant feedback and having the resources in the one place.

The most common negative feedback was in relation to rounding issues in the H5P and Numbas questions, which highlights the importance of stating the accuracy required for each question and ensuring that the range of accepted answers reflects this. While some learners may have the knowledge to overcome small differences in answers, others could find this confusing and off-putting. More than anything, the feedback process highlighted how important it is to incorporate feedback into the creation of digital resources, from the point of view of content, layout and navigation. A striking example of this emerged during the interviews; one of the students had not noticed the links to the Numbas questions on the page. Finally, when asked about improvements to the resources, the following ideas were suggested: link the resources to lectures so the students can access them as they progress through the module; provide a tutorial or tooltip guide on how to use the resources; and incorporate a chatbox style function to allow students to ask a question and receive a response from a lecturer.

5. Conclusions and Future Work

In response to student preferences and considering the online learning environment at MTU, three interlinked digital resources were developed as an aid to independent learning. The resources scaffold self-directed learning in three complementary ways: by enabling students to gauge their own understanding through self-test questions with instantaneous feedback, by providing explicit instruction using short explanatory videos and by facilitating further practice of similar questions through Numbas.

Early feedback from a small number of students indicates that this format is effective for self-directed learning but it is important to ensure that the resources are working correctly and that students have clear instructions on how to use them. Those last two points may seem obvious but the feedback highlighted how issues that may seem small to one learner can be extremely confusing and frustrating to another. These small issues can easily be addressed in a face-to-face setting but can be overwhelming when encountered online. For ongoing feedback, as the resources are rolled out to students on a large scale, a short user experience survey has been incorporated into the resources pages. This will enable lecturers to fix bugs/errors and improve the resources as issues arise.

During the next phase of the project, we will roll out the resources to all first years taking the targeted business and engineering modules and the scope of the digital resources will be expanded to include material for further mathematics modules within MTU. To ensure that students are aware of the resources and understand how to use them, lecturers will provide links to the materials from the modules' Canvas pages and demonstrate the materials during lectures. Additionally, short instructional videos outlining how to use the resources will be provided on Canvas (see www.spiritmaths.com).

An important consideration for future work is the accessibility and usability of the digital resources. Having sought feedback from the Disability Support Service at MTU, we note that the silent animated videos may not be universally accessible and it is preferable to include both narration and captioning in explanatory videos to allow students to process the information in different ways. In addition to the videos, it is important to have an accompanying written explanation in the form of a pdf or MS Word file that can be downloaded for use with assistive technology. Video content management software such as Screencast-O-matic, and Panopto have incorporated speech captioning into their software using automatic speech recognition software. In our experience, automatic speech recognition software can struggle with captioning mathematics and often needs to be edited. Panopto also offers a human transcribed captioning service at additional cost. Decisions surrounding resource accessibility will need to be made on a case-by-case basis, taking into account the learning management systems and software available at an institution and weighing up longevity and frequency of resource use with financial considerations. In our experience, consulting with the Disability Support Service provided us with advice specific to our institution.

Measuring the impact of resource use on students' mathematical knowledge is difficult but can be approached following previous studies that assess the impact of Mathematics Support Centres (MSCs) on student grades and perceptions of mathematics, see Matthews et al. (2013) for an overview. The impact on student grades has been assessed by analysing either student pass rates or the grades themselves in the context of visits to MSCs. Studies by Dowling and Nolan (2006), Patel and Little (2006), Lee et al. (2008), Pell and Croft (2008) Mac an Bhaird, Morgan and O'Shea (2009) and Jacob and Ní Fhloinn (2019) all found that availing of the supports offered at the MSC had a positive effect on student grades. The study designs varied from comparisons of the pass rates of cohorts using the MSC to those who did not, to more complex analyses using regression models that accounted for other potential influential variables. Due to the observational nature of any data collection, measuring the impact of resource use on students' mathematical knowledge will be affected by a number of confounding variables; highly motivated students may be more likely to make use of the resources, students using these resources may also be making use of other resources, different lecturers have different in-class approaches etc. This issue has been acknowledged by previous studies and the inclusion of a student's performance on past exams may provide a measure of some of the potential confounding variables (e.g. Lee, et al., 2008; Mac an Bhaird, Morgan and O'Shea, 2009; Jacob and Ní Fhloinn, 2019).

Since the digital resources are embedded within Canvas, it will be possible to measure some useful indicators of student engagement with the materials using Canvas Analytics, including which resources were accessed by each student and how often they accessed each resource (see O'Sullivan, Casey and Crowley (2021) for details on how this information can be collected). There is potential to cross-reference individual Canvas Analytics data with end of semester module grades and grades obtained in matriculation examinations; however, issues regarding GDPR will need to be taken into consideration. Given the difficulties associated with quantifying the impact of the resources, it is important to also assess the impact of the resources qualitatively through student feedback (Ní Fhloinn, 2009; Matthews et al., 2013; Ní Fhloinn et al., 2014). Again, since the digital resources are embedded within Canvas it will be possible to gather student feedback through an online questionnaire accessed via the same page as the resources or to simply expand the user experience survey currently offered. The data obtained in such a survey could overcome any GDPR issues faced in obtaining sensitive information, such as student's performance on past exams, as this information could be obtained with the respondent's knowledge and consent. The large sample of basic information obtained using Canvas Analytics would be complemented by the smaller but richer information obtained via student feedback to provide a comprehensive assessment of the impact of the digital resources.

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