MSOR Connections

Articles, case studies and opinion pieces relating to innovative learning, teaching, assessment and support in Mathematics, Statistics and Operational Research in higher education.

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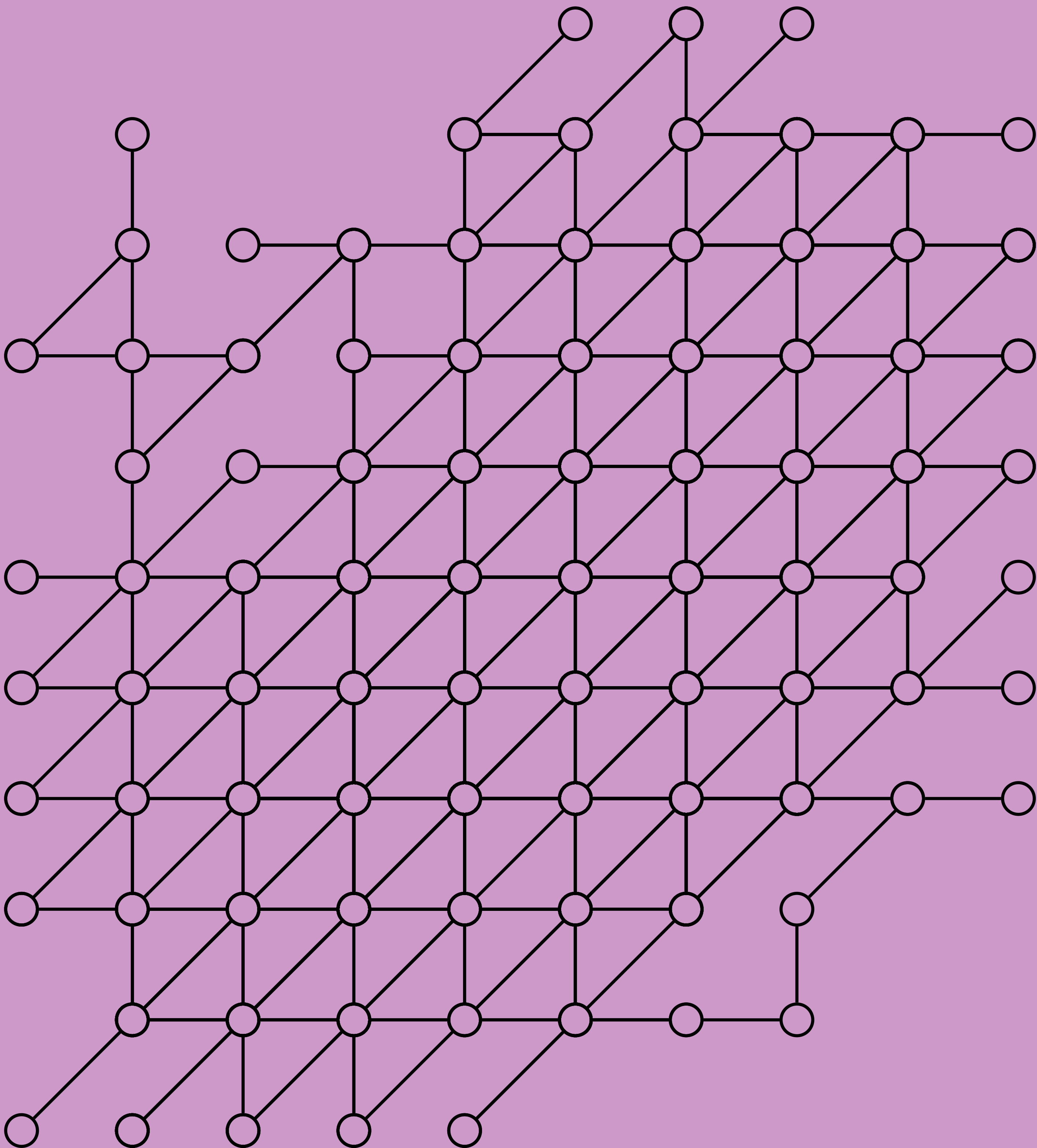

Contents

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EDITORIAL

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I'm delighted to be able to edit this issue, which contains six contributions covering a very interesting range of topics with potential direct impact on colleagues' practice in teaching, learning and assessment. The issue begins with three case studies, the first of which provides an interesting investigation from Cornock et al, looking at the impact of eliciting students to make mistakes to encourage a positive attitude to making errors and learning from them. This is followed by another really interesting case study by Sikurajapathi et al, which also focuses on common errors made by students, but this time in the context of e-assessments and utilising that information to enhance the feedback provided to students. The final of the three case studies comes from Bakhshi et al, which examines the success of the development of formal mathematics and statistics support sessions at the University of the West of Scotland over the last few years. This issue then changes focus a little with two research articles. Since I personally identify as I Statistician, I am very pleased to say that the first of these research articles focuses on teaching and learning in the statistics classroom. In this case, Shaker et al evaluate the use of Kahoot, a game-based learning platform, as a tool for improving students' experience of studying statistics. This is followed by an article by Rowlett and Corner, who present a rather interesting perspective on the changing trends in the sorts of topics we have seen published in *MSOR Connections* over the last 20 years. The issue then closes with a fascinating opinion piece by Bradshaw and Mann, which reflects on some of the obstacles which may lead some students, particularly those from non-traditional academic backgrounds, to question whether they "belong" to the mathematics community.

I'm also delighted that the publication date of this edition of *MSOR Connections* coincides with the return of the annual CETL-MSOR conference, being held (both online and in-person) from 2nd to 3rd September 2021 at Coventry University. *MSOR Connections* has a long-standing relationship with the CETL-MSOR conference community and the aims of this journal overlap very much with those of the conference. We are therefore, pleased to announce that there will be a Special Issue of *MSOR Connections* with contributions invited from the 2021 CELT-MSOR conference. Submissions for this special edition, should include a note to that effect in the "Comments for the Editor" field during the submission process. It is anticipated that this will be published in early 2022 with a deadline for submissions of 31st October 2021.

MSOR Connections can only function if the community it serves continues to provide content, so we strongly encourage you to consider writing case studies about your practice, accounts of your research into teaching, learning, assessment and support, and your opinions on issues you face in your work. We welcome submissions to the journal at any time, and in particular we are keen to publish articles reflecting on the issues faced during Covid-19 and the implications for the future, so we would particularly encourage readers to consider sharing their experiences by writing for *MSOR Connections* on such topics.

Another important way readers can help with the functioning of the journal is by volunteering as a peer reviewer. When you register with the journal website, there is an option to tick to register as a reviewer. It is very helpful if you write something in the 'reviewing interests' box, so that when we are selecting reviewers for a paper we can know what sorts of articles you feel comfortable reviewing. To submit an article or register as a reviewer, just go to http://journals.gre.ac.uk/ and look for *MSOR Connections*.

CASE STUDY

Students being set up to make mistakes in class through an error-eliciting task

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Abstract

In order for students to develop a better understanding and the skills to question future work, a session was introduced into a teaching workshop which sets students up to make common mistakes. These mistakes are often made by blindly following procedural methods. The students' views on these mistakes and how they found the error-eliciting task were gained through focus groups on the day of the activity. Factors such as knowing whether they had the right answer and the amount of staff involvement were discussed. In a follow-on focus group two weeks after the session, there were indications that the session had an impact on how they worked generally as there was more discussion within class and a shift in views about making mistakes.

Keywords: Making mistakes, error-eliciting problems, tutor reliance, willingness to try, routine approaches.

1. Introduction

As presented by Fischbein (1994), the 'blind learning of algorithms' leads to problems as lack of understanding can lead to the wrong application of processes. In this paper, we consider the teaching of a topic where this is common. It is situated in a level 6 elective called 'Abstract Algebra' which is based on applications of group theory and monoid theory. More information about this module can be found in Cornock (2021) and Cornock (2015). The students are introduced to the pumping lemma (as part of formal languages) in a usual workshop style session. This requires picking a word and a value that leads to a contradiction to show that a language is not recognisable. Some words work better than others and some cannot be used for various reasons (e.g. you must have a word that is in the language). The students are shown two proofs in which the starting examples are provided. They are also given some exercises to work through without the starting examples or values, but the most sensible guesses lead them to the correct answer. It is the type of proof that can be reproduced with little understanding. More information about the mathematical topic can be found in Lawson (2004).

Error-eliciting problems are 'designed to specifically bring forth among students common mistakes pertaining to a particular mathematical concept' (Lim, 2014). Eggleton and Moldavan (2001) provide examples of teaching practice within middle school where pupils consider mistakes. The idea is that students are left to investigate, with very little guidance. On the basis of questions asked by the teacher, pupils can explore further and ideally reach conclusions. One of their activities was an exercise where the pupils had to decide the order of the numbers. Common mistakes were factored in. For example, numbers such as 4% and 4/10 were included. They state that 'some teachers have become so accustomed to the common mistakes made by students that their strategy for teaching precision is to warn students about possible mistakes in advance'. Instead, the pupils are required to 'confront a possible error'. This difference means that pupils build the skills to question future work and resolve issues themselves. These concepts, presented by Eggleton and Moldavan (2001), form the premise for a teaching session within Higher Education. More examples of error-eliciting problems can be found within Lim (2014).

In this paper, we present information and evaluation on a teaching session on the pumping lemma in which students are set up to make common mistakes through an error-eliciting exercise. The activity takes place a week after the initial introduction session that is described above. The students are provided with a different language to work with. Instead of letting the students choose their starting word and value, they are given six words and three values. Some of these lead to contradictions, but most of them do not and are based on common mistakes seen in work done by previous cohorts when the students have just followed the process with little thought. With all the examples, the students can work through the method as given in the lecture, but with many of the provided examples there is a reason why they do not lead to a contradiction. The session takes place in a room with many whiteboards, where the students work on the problems in small groups of around four students. There are two lecturers present, who are on hand to answer questions and circle the room. They ask the students questions about why they have taken the approaches they have, and discuss any problems and incorrect answers (especially if they have not been spotted by the group). This approach is very similar to the example presented by Eggleton and Moldavan (2001), just with material for a higher level.

2. Methodology

Two focus groups took place on the same day as the session being considered in this study in 2018/19, containing eight students in total. Another focus group took place two weeks later and contained six of the students from the first two focus groups together and no additional students.

At the start of all three focus groups, it was pointed out that there are different types of mistakes and that not paying enough attention to the technicalities of the method was of interest within the focus group. The students were reminded that in the 'Abstract Algebra' session that they did an exercise that required trying the given examples. It was pointed out how the activity was created based on the tutors' knowledge of why certain mistakes were made and carefully designed so that the students were likely to make common mistakes.

2.1. Focus groups on the same day as the activity

After being presented with the information above in the focus group on the same day, the main question was regarding how the students found the experience in which they were led to make mistakes. In particular, they were asked how they felt about making a mistake and how they respond to one, both generally and in the session. There were questions about whether they felt differently about making mistakes now that they have been led to make one, if anything had changed in their view of mistakes and what they had learnt from the experience. They were asked whether they view being led to make mistakes as an opportunity to learn, both in general and when they were led to make a mistake in the session.

2.2. Focus group two weeks after the activity

Two weeks later, the students were reminded of the same information at the start of the focus group that had been presented at the start of their first focus group. The main question in this focus group was whether the experience of being led to make mistakes had impacted or changed their approach when trying questions since the last focus group. They were also asked again about how they found the experience of the session and what they learnt from the exercise, and whether their opinion of the session had changed. There were questions about mistakes they had made in the last two weeks and how they had approached new problems, particularly ones they were not confident about, and for any differences. The students were also asked whether they thought the experience had affected the way they felt about making a mistake.

3. Results and discussion

There were mixed opinions about making mistakes, with some of the students in the focus groups being negative about it. They felt that *"if you get stuck with Maths, you get stuck"* and there is *"no sort of leeway"*. When talking about the exercise done in class that day, a student mentioned that they are *"always quite apprehensive"* about starting a question if they cannot see the end point. There were some themes that emerged in these focus groups that had appeared elsewhere (Cornock et al., submitted). For example, there was a willingness to try on a whiteboard; one student liked how they *"could have done it completely wrong and it's been rubbed off a board and no-one's going to know".* There were also comments from some of the students, around the same themes in the other study, about how they do not want mistakes in their notes and there was concern about saying *"something stupid"* in front of people they do not know.

However, there was the acknowledgement that mistakes are going to happen and you can learn from them, especially within 'Abstract Algebra'. They said that they have to try different approaches and *"need to make mistakes"* in order to go down a different path and get an answer. One student said that they can compare work containing errors with correct work they produce.

3.1. Thoughts on the session

When asked their thoughts on the exercise they worked with during the 'Abstract Algebra' session, the students thought that it was *"well tailored to actually making a mistake"* and resulted in more errors being made than usual. They also acknowledged that it gave them practice of correcting the errors. One student said that they did not like being led towards making a mistake, whereas another described the session as a *"good change"* as they were actively engaged. Another found the questions *"challenging"* and got *"frustrated"* when they got stuck with the work.

The students said they discovered that making mistakes is an essential part of the learning process, specifically that they can learn from those mistakes to head *"in the right direction"*, although there were indications that they already thought they can learn from mistakes. Comments included that they see the importance of trying different approaches and how that this is better than not doing anything. Comments included that *"it doesn't matter if it's wrong"* and it allows them to *"rule something out"*. One student said that before the class they *"would immediately panic and try and go for it"*, but now they recognise that they do not need to panic. Another student felt that they still approached the work in the same way as before the session, which involved attempting the question to *"see what happens"*. The session seemed to make little difference to some students, but other students were specifically helped by seeing that an incorrect example would help them find one that would work.

There were concerns about having a similar question in an exam. In particular, one student was worried about whether they would keep trying the question. Another student acknowledged that there were in a better place for having done the session as they gained more awareness of what could be done and what to look out for. That student said that they would have more confidence to try a question as they now have a *"better understanding"*. The students said that it allowed them to reflect about what they could try and why they were taking the approaches. They acknowledged that it helped them with understanding, even if this did not lead to them getting a correct answer. This is a large step away from students blindly following examples. The students *"think some people need to be more encouraged to get up and go for it"* as some students do not. They recognise that not all students will carry out the same reflection and so *"some people might have learned more from today than others"*.

There was an acknowledgement that the students would have liked more lecturer support in the session as they wanted a member of staff to correct their errors and said that they would start talking about something else without frequent input.

3.2. The group work aspect

The students thought that the group element helped with the exercise. One mentioned that *"if you were making a mistake by yourself, it's hard to actually get around it and start working on the actual process"* and how *"if you had someone to talk to…I think together you could probably get past most things"*. One of the students gave an example of working for 14 hours on an assignment question as it was individual work and hence they were unable to discuss it with others on the course. They said that they had just been *"sitting there and sitting there and sitting there".*

There was a discussion in one of the focus groups about being with a familiar group. They admitted that *"it is very easy to sit back"* and have conversations about other things when they know everyone in their group and are more actively involved when working with people they do not know. However, there were concerns that they would *"say something stupid"* if they were with a group of people they did not know and therefore would be reluctant to say anything. They felt that the right balance would be a mixture of people they did and did not know in their group. The students suggested that this would give them enough motivation to contribute but alleviate some of their fears as they would have people there to defend them.

3.3. Concerns about not knowing if they were incorrect

Within the two initial focus groups, there was concern about not knowing whether their work was correct. One student said that *"I could think I've done really well today and actually did it all wrong and didn't realise".* The students were concerned about using incorrect information from the session later in an assignment. One student pointed out that they *"tend to stick quite religiously to what we wrote down in the lectures"* and that they need correct answers to exercises.

There were some mixed comments about the lecturers not going through the answers afterwards. One student said that *"it's only safe to make mistakes if you're going to have the correct answers given to you at the end"* and another said that they would not be as reluctant to try if they knew they were going to be provided with the correct answers. However, there were some concerns that if they knew they would get the answers, then groups may not have been as motivated and would have waited for the answers. A theme that emerged was that there was a reliance on lecturers and a need for receiving correct answers from them.

There was an interesting comment made by a student about how they did not know the reasons for the errors in the session. They did not know whether it was because they were led to make the mistake or that they were making their own errors that were not intended. One student said that they would automatically think they had done something incorrectly rather than think it is an example that could not be done.

The students thought that there is *"more exploration"* in Mathematics at university, that there is a lot more choice within work and possibly lots of ways to get to an answer. Also, at university level, they do not necessarily know when they have made a mistake and can do a lot of work without realising there is an error. The students also did not like how they may not be able to see a mistake that has been pointed out to them. One student said that this makes them feel *"a bit discouraged".* A student said that they may get asked why they have done something in their working (for example, by a lecturer), but they do not necessarily know as they have been blindly following the book. There is a tendency to follow methods provided by lecturers without understanding, and there is dislike amongst students that this may lead to an error and they may not necessarily be aware of the mistake.

3.4. Reflection two weeks after the task

In the focus group two weeks after the task, the discussions suggested that there had been changes. Some students said they now use different resources; for example, one student said they now use a pencil and another pointed out how they started to use the individual whiteboards to show their thoughts to other people. The students suggested that a large change is that more people are working together. They are checking their answers with someone else, pointing out errors to each other and explaining things more. They noticed that the whole class is a lot louder, there is more interaction and *"it doesn't sound like people are just sat working by themselves".* One student acknowledged that it is *"easier to work with people a little bit more"* as a consequence of the activity.

The students said that there is now more of a willingness to try, including when they are stuck. One student said they now just try anything. Another comment was that they try various approaches as they can rule them out if they are incorrect and that could lead on to another idea which results in a correct answer. They said that if ideas *"don't work, then you can just throw it away"* and *"it doesn't matter"*. The students felt that the session re-enforced how they *"will make mistakes",* that is unlikely that they will be able to get the answer first time and they will have to try different attempts. They feel that they do not have to be concerned about making a mistake. They see making mistakes as progress as they are *"one step closer to finding the right answer"*.

The students found the class *"useful"* when starting preparation for the subsequent assignment, in which the students create their own examples in groups (see Cornock, 2021). They are now aware that when an example does not work, they can go back and reflect about the starting point. They would consider whether the example is adequate rather than just thinking that they had just made an error in their working.

Before the activity, the students generally viewed mistakes as negative, but could still see how they could learn from mistakes. The activity re-enforced this benefit and has resulted in a change of behaviour and attitudes within class. There is now more of a willingness to try and more discussions taking place.

4. Conclusions

Some students already had a very healthy view of making mistakes, but specific realisations following the error-eliciting exercise included that they could use an incorrect example to help them understand and use that to find one that would work. Rather than blindly following examples that they had already, the students are now questioning starting points and examples.

There was concern about making mistakes at university and not knowing they had made an error. Even at Level 6, there was a reliance on the lecturer, particularly in providing correct answers to the students. However, the group work element of the activity helped with their progress. After the session containing the error-eliciting task, students were talking to each other more and there was an increased willingness to try exercises. The activity will continue within the module. In the response to the comments made, the students will be provided with full solutions at the end of the class without advance warning that they will be available.

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CASE STUDY

Students' Perceptions of Enhanced e-Assessment Feedback Addressing Common Student Errors in Mathematics

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Abstract

The Common Student Errors Project (CSE Project) has been running at the University of the West of England (UWE, Bristol) since 2017. The main aim of this project is to introduce a method to detect CSEs and to provide tailored feedback in Engineering Mathematics e-Assessment questions. In this case study we briefly describe the process of collecting CSEs related to Engineering Mathematics and delivering personalised enhanced feedback to students who made CSEs on Dewis e-Assessment questions. We then present how we carried out a questionnaire to gather student perceptions on the enhanced feedback they received. Finally, we present the outcomes of the questionnaire data, the conclusions on students' perceptions of the current enhanced feedback and ascertain possible future directions for further development of the enhanced feedback.

Keywords: e-assessment, Dewis e-Assessment system, Common Student Errors, enhanced feedback.

1. Introduction and Background

The main aim of the Common Student Errors Project (CSE Project) is to introduce a method to detect CSEs and to provide tailored feedback in Engineering Mathematics e-Assessment questions. We have focussed on Engineering Mathematics questions using Dewis as the demonstration platform, however, the method could be useful for other e-Assessment systems and in other contexts and disciplines (CSE Project at UWE, 2019).

Developed at UWE Bristol, Dewis is a fully algorithmic open source e-Assessment system which was primarily designed for numerate e-assessments (Gwynllyw and Henderson, 2009; Gwynllyw and Henderson, 2012). Even though Dewis has been used very successfully over the past decade, it is not being used to its full potential. Therefore, one aim of the CSE project is to develop and use additional features, in order to fully realise the benefits of Dewis.

A Common Student Error (CSE) is an understandable error leading to an incorrect answer due to a student's misconception. For example, answering $a^2 + b^2$ when asked to expand $(a + b)^2$ can be considered as a CSE. This kind of an understandable but incorrect implementation of a process is also called a mal-rule (Rees and Barr, 1984; Sleeman, 1984).

Finding students' perceptions on enhanced feedback delivered through Dewis is the fourth stage of the CSE Project. In the first stage of the research, as described by Sikurajapathi, Henderson, and Gwynllyw (2020), we gathered CSEs made in the Engineering Mathematics 2018 January e-examination, by examining students' written answer scripts along with their corresponding Dewis answers. We found 40 CSEs relating to 17 questions (Sikurajapathi, Henderson, and Gwynllyw, 2020).

Having identified CSEs related to the module, in the second stage we altered the original Dewis question code, including additional scripts using the Perl programming language. Performance Indicators (PIs), are a powerful feature of the Dewis administration reporter tool, as they enable the academic to view the performance of a student on each question attempt. This is particularly useful in order to see whether a particular student scored zero by not answering the question or by answering the question incorrectly. For each identified CSE, we introduced additional PIs to the altered Dewis question code, in order to automatically capture each CSE and provide detailed enhanced feedback when they are triggered.

For the third stage of the project, the amended questions were included in the semester 1 weekly e-Assessments used as summative assessments for the 2019-2020 cohort of the Engineering Mathematics module. Further, nine of the amended questions were presented in a revision test at the end of the first semester. The fourth stage of this study, which we are going to discuss in this paper, comprises an online questionnaire given to those students who received enhanced CSE feedback in either the weekly e-assessments or the end of semester revision test.

2. Objective and Research Questions

The primary focus of our research is to design enhanced feedback to address CSEs and underline mathematical misconceptions of engineering students at UWE Bristol. In other words, we want to develop enhanced feedback which promotes students' conceptual change and facilitates student learning. Further, we want the enhanced feedback to be user-friendly with a coherent structure (clear, organised, detailed and yet simple), and to have ergonomic features (user-friendly format, font, font-size, and appropriate labelling and highlighting).

For example, the enhanced feedback given for a question regarding finding the modulus of a given complex number is shown in Figure 1. The CSE related to this problem was to take $(-2)^2$ equal to -4. For the enhanced feedback we used different colours, a step by step method and equation numbering to provide clear and concise feedback to address students' misconceptions.

The aim of the questionnaire study was to gather students' views on the enhanced feedback they received as a result of triggering a CSE. The main research questions were:

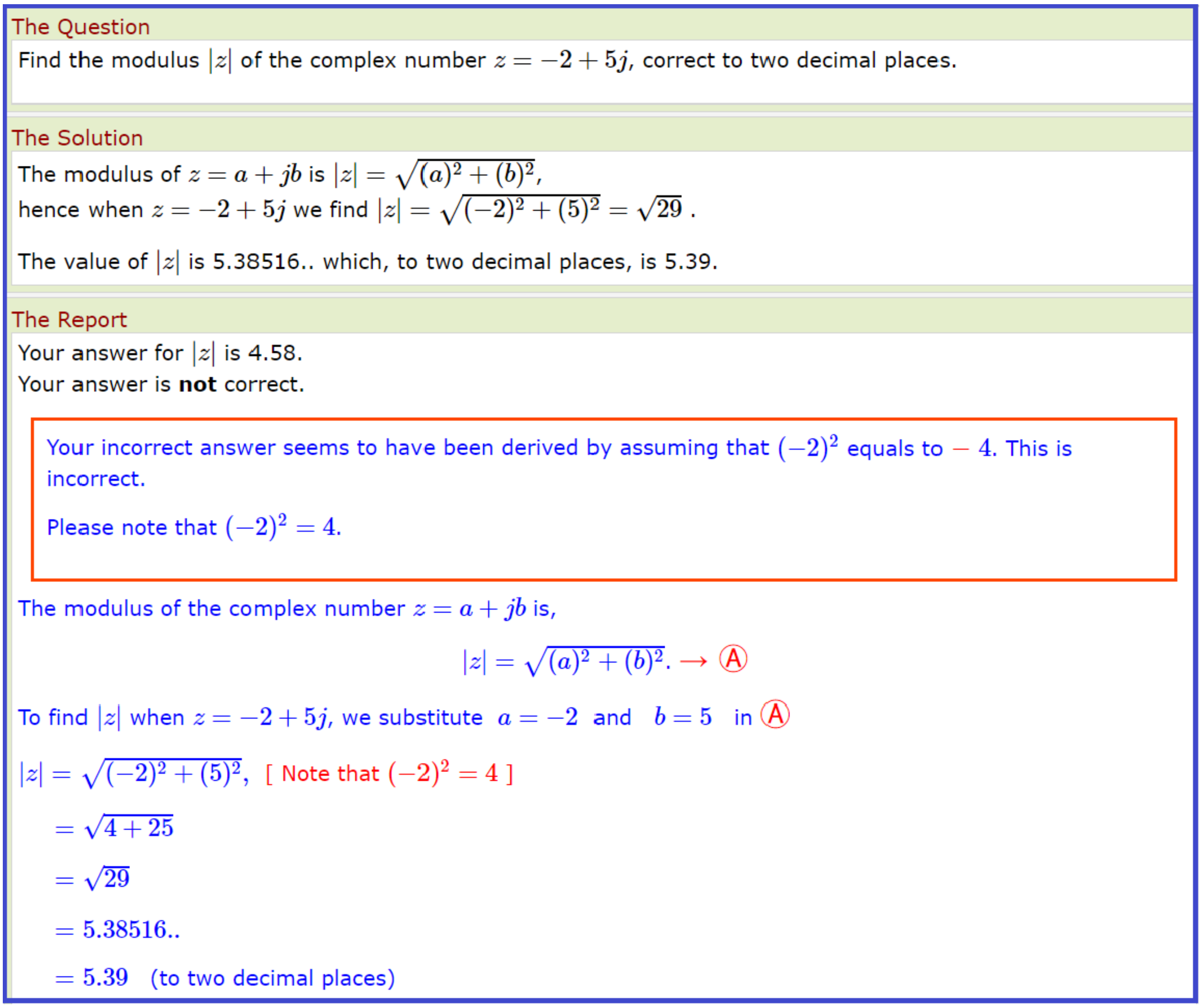
- How and to what extent does the current enhanced feedback help students to change their conceptual understanding and facilitate their understanding of the subject?
- What are their views on the user-friendly features of the enhanced feedback?

3. Research Method

The questionnaire was planned to gather students' views on how and to what extent the current enhanced feedback helped them to change their conceptual understanding and facilitate their understanding of the subject. In addition, we wanted to gather students' views on the user-friendly features of the enhanced feedback.

3.1. Ethical Review of the Research

The questionnaire was designed in accordance with policy, procedures and guidance of the Faculty Research Ethics Committee (FREC) at UWE, Bristol. The questionnaire distribution and collection of data for the research was commenced after receiving written approval from the FREC to undertake research involving human participants.



The Question

Find the modulus $|z|$ of the complex number $z = -2 + 5j$, correct to two decimal places.

The Solution

The modulus of $z = a + jb$ is $|z| = \sqrt{(a)^2 + (b)^2}$,
hence when $z = -2 + 5j$ we find $|z| = \sqrt{(-2)^2 + (5)^2} = \sqrt{29}$.

The value of $|z|$ is 5.38516.. which, to two decimal places, is 5.39.

The Report

Your answer for $|z|$ is 4.58.
Your answer is **not** correct.

Your incorrect answer seems to have been derived by assuming that $(-2)^2$ equals to -4. This is incorrect.

Please note that $(-2)^2 = 4$.

The modulus of the complex number $z = a + jb$ is,

$$|z| = \sqrt{(a)^2 + (b)^2}. \rightarrow Ⓐ$$

To find $|z|$ when $z = -2 + 5j$, we substitute $a = -2$ and $b = 5$ in Ⓐ

$|z| = \sqrt{(-2)^2 + (5)^2}$, [Note that $(-2)^2 = 4$]

$= \sqrt{4 + 25}$

$= \sqrt{29}$

$= 5.38516..$

$= 5.39$ (to two decimal places)

Figure1: An example of the enhanced CSE feedback

3.2. Questionnaire Design and Distribution

The questions in the questionnaire, shown in Figure 2, fell into two groups: Likert-scale and open-ended. Participants received four closed questions, using a 5-point Likert-scale ranging from “Strongly agree" to “Strongly disagree". For each of the three open-ended questions, a comment box was provided for students to input their response.

The questionnaire was administrated via Qualtrics software (Qualtrics, 2005). Qualtrics is a web-based survey software tool which can be used to conduct publicly available surveys, or to give specific users access to a survey. Using online questionnaires has numerous benefits in terms of cost, time, ease of administration, data collation and analysis (Dillman, 2007). Another advantage of using an online questionnaire was that it was easy to reach all of the students who made CSEs by emailing them with a link to the questionnaire. However, the collected responses were anonymous.

UWE Bristol | University of the West of England

QUESTIONNAIRE

Evaluating the effectiveness of the enhanced feedback on the Dewis e-Assessment System

This questionnaire has a number of questions asking you for your feedback on the enhanced feedback you received on Engineering Mathematics weekly test (*include assessment number here*) on the Dewis e-assessment system.

Please tick (√) in the appropriate column alongside the question number on the questionnaire.

Do not worry about projecting a good image. Your answers are **CONFIDENTIAL.**
Thank you for your cooperation.

		Strongly disagree	disagree	Neutral	Agree	Strongly agree
1	The enhanced feedback I received on weekly test (*number*) improved my mathematical understanding.					
2	The enhanced feedback makes me feel confident/comfortable with Engineering Mathematics.					
3	The information in the enhanced feedback is relevant to the question asked.					
4	I am satisfied with the overall structure of the enhanced feedback.					

5. What do you **like** about the enhanced feedback you received?

6. What do you **dislike** about the enhanced feedback you received?

7. Do you have any suggestions for improvement?

Figure 2: Example of the questionnaire sent out to students

The questions were designed to avoid long, double-barrelled, technical, ambiguous, leading or double negative questions or statements. In order to make the questionnaire short and clear we avoided lengthy questions and made sure that the questionnaire fitted on one page (Dillman, 2007). Great care was taken to make the questionnaire visually appealing (Frankfort-Nachmias, 1996). The UWE logo was inserted at the top of the questionnaire to make it more professional and institution-related. In the invitation email it was specifically stated how the participants' responses would be used in the future development of Dewis and hence be valued as a whole by the UWE community (Oppenheim, 1992).

As suggested by Dillman (2007), in order to maximise response and completion rates, a clear indication of how long the questionnaire would take to complete was given in the invitation email. Further, clear instructions were included, together with the purpose of the questionnaire and important information related to the research which were available in a separate 'Participant Information Sheet' (PIS). A link to the PIS, which was placed on the CSE project web page (CSE Project at UWE, 2019), was included in the 'Informed Consent' section at the beginning of the questionnaire.

For each assessment, we identified which students had received enhanced feedback on each question by analysing the additional PIs in the Dewis Reporter. At the end of each weekly test we sent a questionnaire to those identified students. There were some students who received CSE enhanced feedback, and hence the questionnaire, in more than one week. The total number of questionnaires sent by the end of the semester was 336 and these were sent to 196 distinct students, who received CSE enhanced feedback in at least one of their weekly tests.

At the end of the revision test, we identified 129 distinct students who had received enhanced feedback for this test. Since we wanted to gather more responses from the students, we decided to send the questionnaire to all of the students who had received enhanced feedback in some form. There were 78 students who received enhanced feedback for both the weekly and revision tests. Therefore, in order to avoid sending the questionnaire to those students twice, we sent the same questionnaire to the 247 distinct students who had received enhanced feedback for either the end of semester revision test or the weekly tests.

4. Data Analysis

In total, we received 33 responses to the 336 weekly questionnaires and 26 responses to the 247 end of semester questionnaires. The 2019-2020 cohort had 330 students and 247 of these students made at least one CSE in either their weekly tests or the revision test. In total, we received 59 responses to all of the questionnaires sent.

4.1. Analysis of the Likert-scale questions

The first four questions of the questionnaire were in Likert-scale format. Therefore, quantitative methods were used to analyse the participant responses. In the following sections we discuss each of these questions in the questionnaire separately and present figures which show the percentages of each Likert-scale response with the agreement percentage for each statement. It should be noted that percentages do not always total to 100% due to rounding. The agreement percentage (AP) is the number that selected "Agree" or "Strongly Agree" divided by the sum of those participants selecting a response on that question.

Q1: The enhanced feedback I received on weekly test [x] improved my mathematical understanding

Figure 3 presents the participants' responses to the statement '*The enhanced feedback I received on weekly test [x] improved my mathematical understanding*' in the weekly questionnaire and/or the end of semester questionnaire.

This shows that the majority of participants either strongly agreed or agreed that the enhanced feedback they received improved their mathematical understanding. The AP of the participants to the statement is 88% and this figure indicates the participants' positive appreciation towards the conceptual change afforded by the enhanced feedback.

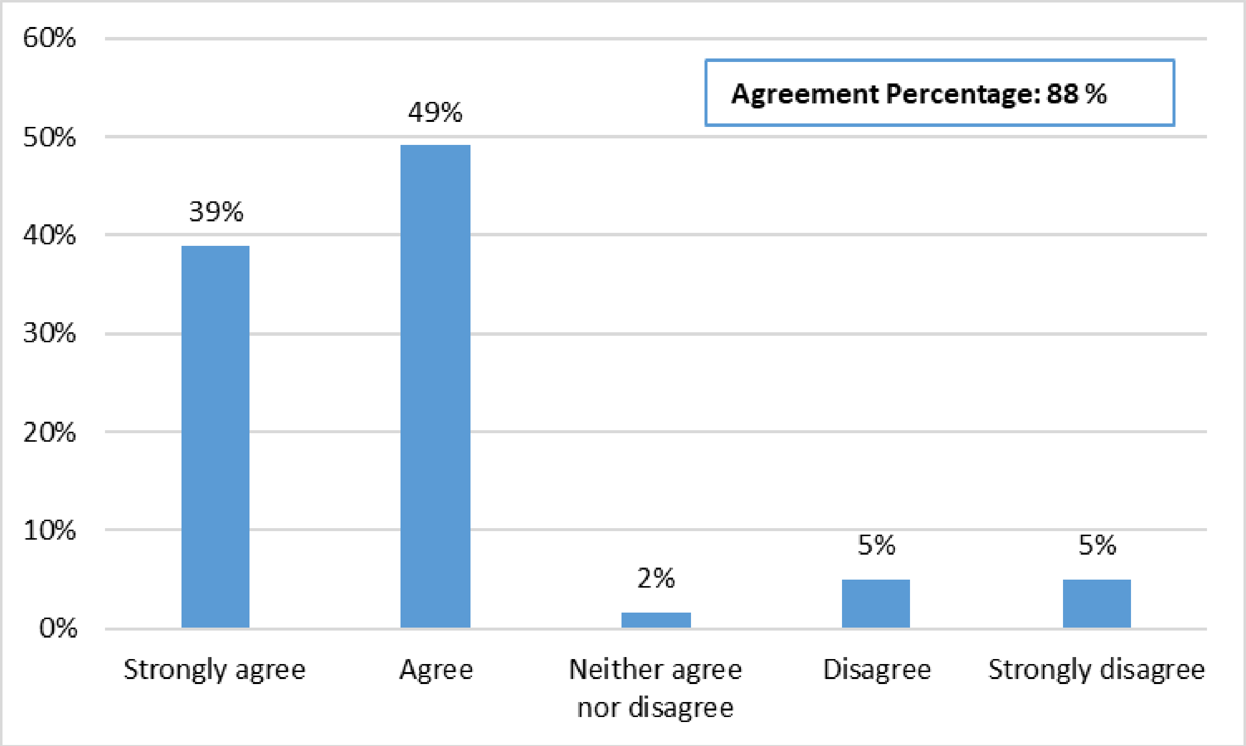


Figure 3: Questionnaire responses to the question "The enhanced feedback I received improved my mathematical understanding"

Q2. The enhanced feedback makes me feel confident/comfortable with Engineering Mathematics

Figure 4 shows the participants' responses to the statement '*The enhanced feedback makes me feel confident/comfortable with Engineering Mathematics*' for the weekly questionnaire and/or the end of semester questionnaire. The results show that the majority of the participants agreed with this statement and the AP of the participants to the statement is 73%.

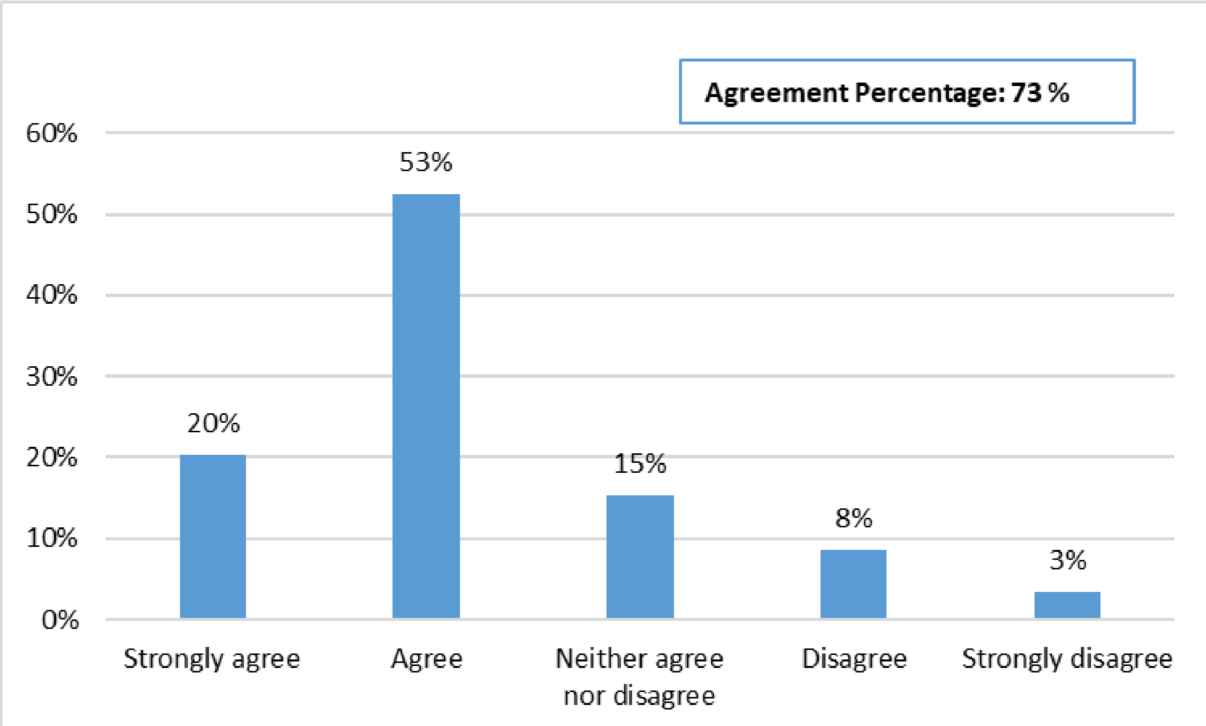


Figure 4: Questionnaire responses to the question "The enhanced feedback makes me feel confident/comfortable with Engineering Mathematics".

Q3. The information in the enhanced feedback is relevant to the question asked

The third statement of the questionnaire is where we are looking for how students feel about the relevance of the enhanced feedback. Figure 5 shows the questionnaire responses to the question *"The information in the enhanced feedback is relevant to the question asked"* for the weekly questionnaire and/or the end of semester questionnaire.

What stands out in Figure 5 is that almost all of the participants agreed or strongly agreed that the information in the enhanced feedback is relevant to the question asked (AP 95%).

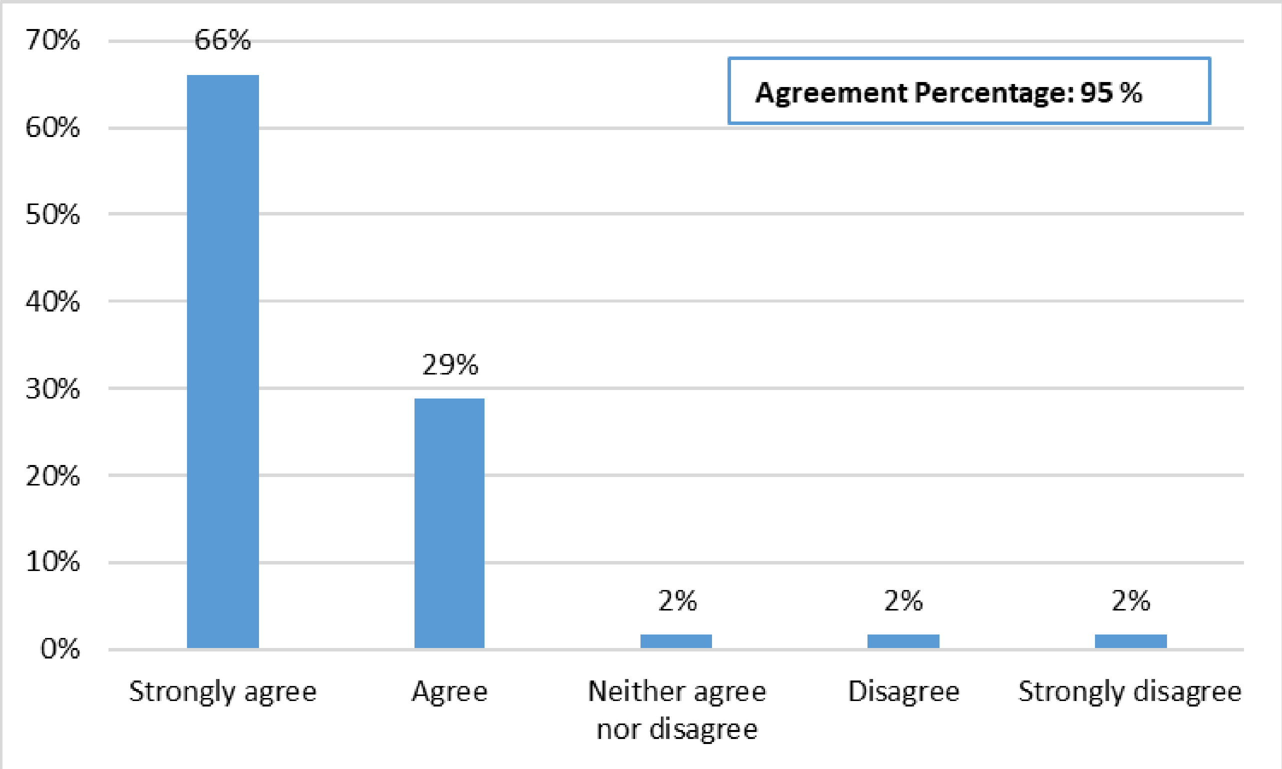


Figure 5: Questionnaire responses to the question "The information in the enhanced feedback is relevant to the question asked"

Q4. I am satisfied with the overall structure of the enhanced feedback

Figure 6 shows the questionnaire responses to the question *"I am satisfied with the overall structure of the enhanced feedback"*. The majority of those who responded to this statement indicated that they were satisfied with the overall structure of the enhanced feedback. The figure shows that the AP for this statement is 87%.

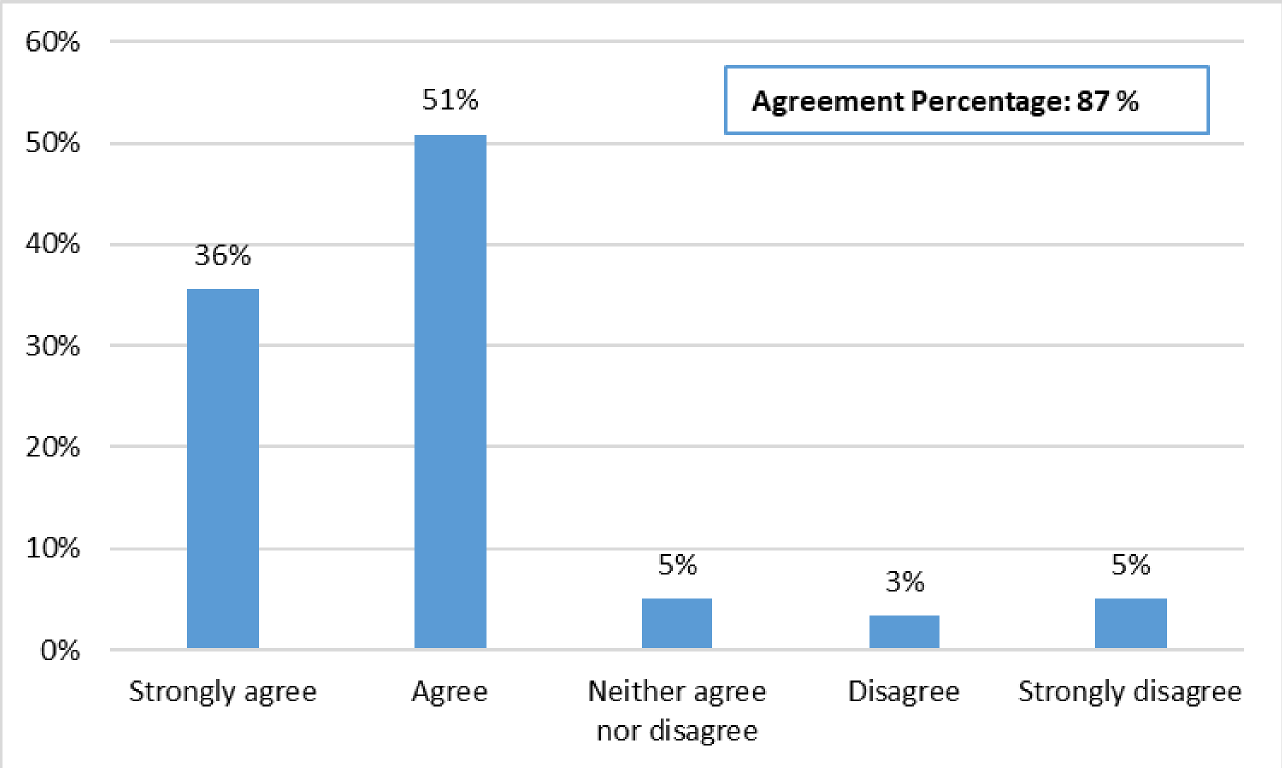


Figure 6: Questionnaire responses to the question "I am satisfied with the overall structure of the enhanced feedback"

4.2. Analysis of the open-ended questions

We used thematic analysis to analyse the three open-ended questions. Thematic analysis is a widely used qualitative method. It is used to analyse qualitative data gathered in the form of open-ended responses to questionnaires (Castleberry and Nolen, 2018).

Thematic analysis is used for identifying, analysing and reporting patterns or themes within data. In their paper, Braun and Clarke (2006) describe how to conduct thematic analysis in six phases (Familiarizing yourself with your data, Generating initial codes, Searching for themes, Reviewing themes, Defining and naming themes, Producing the report). Following the six phases as described by Braun and Clarke (2006), we conducted thematic analyses on the responses to the open-ended questions on the questionnaire for both the weekly and the end of semester questionnaires combined.

Q5. What do you like about the enhanced feedback you received?

From this question, we want to capture what students like about the enhanced feedback so that we can keep those features unchanged when new enhanced feedback is constructed in the future.

Two overarching themes, *Conceptual change* and *User-friendly features*, emerged from a detailed thematic analysis of the texts of students' responses to this question. The sub-themes which emerged from the two aforementioned main themes are summarised in Table 1.

Table 1: Themes resulting from thematic analysis on student responses to the question "What do you like about the enhanced feedback you received?"

Main Themes	Sub-themes
Conceptual change	Correct CSE capture (Correct capture) Facilitate learning (Beneficial) Relevance of the content on CSEs enhanced feedback (Relevance).
User-friendly features	Coherent structure Accessibility

The *Conceptual change* theme highlighted three sub-themes which examined perception on Correct CSE capture (Correct capture), facilitating learning (Beneficial), and Relevance of the content on CSEs enhanced feedback (Relevant).

Under the sub-theme Correct capture, many participants felt that the enhanced feedback they received cleared up their doubts. Further, they claimed that the feedback made them understand why and where they went wrong. The majority of the participants' appreciated the way in which the enhanced feedback helped them to change their misunderstandings/misconceptions of the mathematical concepts and to improve their learning. In the Beneficial sub-theme, a significant number of participants mentioned the benefit they received from the enhanced feedback in improving their understanding. Further, they noted the usefulness and helpfulness of the feedback to their learning and understanding of the subject. In the Relevance sub-theme, a couple of participants mentioned how relevant the received feedback was in their learning. Table 3 in the Appendix contains several examples of such quotes which emerged from the *Conceptual change* theme and three examples of such quotes are given below:

"It makes you feel conscious of errors you made. The fact that it tells you what you've done based on your final input is clever."

"The enhanced feedback got right to the reason the answer was wrong rather than lingering on things already explained above in the solution."

"The Feedback which I received helped me to understand where I was most likely to make errors and showed the correct way of working out solutions."

The *User-friendly features* theme contained two sub-themes: Coherent Structure and Accessibility. Under the sub-theme Coherent Structure, it emerged that many participants liked the structure of the enhanced feedback and particularly highlighted its step-by-step, clear and concise explanations. Several participants appreciated the accessibility features of the enhanced feedback. In particular they commented on its instant availability, quick accessibility, and visibility in different colours. Table 4 in the Appendix shows multiple examples of those quotes which arose from the User-friendly Features Theme. One example from Table 4 is reproduced here:

"The total feedback was overall concise and accessible."

Q6. What do you dislike about the enhanced feedback you received?

From this question we wanted to capture what students disliked about the enhanced feedback so that we can amend and improve the features of future enhanced feedback. Thematic analysis on the responses for this question highlighted four main themes: *Everything is alright*, *Short explanations*, *Less accessibility features* and *Not helpful*.

It was encouraging to see that the majority of the participants said that they were satisfied with the current CSE enhanced feedback and did not indicate any aversion to it. Some comments from the *Everything is alright* theme can be found in Table 5 in the Appendix.

A few participants indicated that the enhanced feedback is very short for some questions and suggested that they would prefer to have more detailed feedback, which would improve it in the future. Two such examples of participants' comments are shown below:

"Some answers can be quite brief so more in depth answers would be great."

"Needs more steps for the student to fully understand what is happening throughout the equation."

The participant who made the above comment also disagreed to all of the Likert-scale statements on the questionnaire except for statement Q3.

Further comments on the *Short explanations* theme can be found in Table 6 in the Appendix.

A few comments related to the *Less accessibility features* theme. Some participants mentioned the issue of visibility of the current enhanced feedback and gave some useful suggestions for increasing its visibility. One participant suggested that moving the enhanced feedback to the general Solution section rather than including it in a separate section (Report section) to avoid scrolling past the enhanced feedback. These inputs were very valuable to us and we will aim to incorporate them and address the issues raised in the future development of the CSE project.

Table 7 in the Appendix shows multiple examples of quotes which arose from this theme. One example of which is given here:

"The incorrect answer could be written right after the correct one rather than right at the very bottom so that it would be easier to understand."

However, only one participant found the enhanced feedback not to be useful and stated that *"It doesn't help me to learn anything."* The same participant strongly disagreed to statements Q1 and Q2 and disagreed to statement Q4. However, the participant agreed with statement Q3.

Q7 Do you have any suggestions for improvement?

The last item of the questionnaire was ‘Do you have any suggestions for improvement?’ Here we were looking for participants’ views on what is lacking in the feedback and for ideas on how to further develop the enhanced feedback in the future. Thematic analysis on the responses for this question revealed three main themes: *Everything is alright*, *Suggestions to improve current features* and *Suggestions for future directions*. Table 2 summarises these themes and all of the sub-themes which emerged from this question.

Table 2: Themes resulting from thematic analysis of student responses to the question *“Do you have any suggestions for improvement?”*

Main Themes	Sub-themes
Everything is alright	Everything is alright
Suggestions to improve current features	Detailed Explanations More Accessibility features
Suggestions for future directions	Enhanced feedback for all the other questions New ideas for further improvement

Most of the participants were satisfied with the enhanced feedback they received and did not give any suggestions for further improvements. A few responses received under the *Everything is alright* theme can be found in Table 8 in the Appendix, and one of these is presented here.

“I think it is as good as it can be. Thank you!”

A few participants echoed the same suggestions that we received for question 6 of the questionnaire. Namely, they suggested providing detailed feedback and making the feedback more accessible, readable and efficient. A few responses received in the *Suggestions to improve current features* theme are detailed in Table 9 in the Appendix and two of these are presented here.

“Include all steps, even if they seem unimportant.”

“Provide enhanced feedback not just on hard questions but on easy ones too.”

One participant who disagreed to the Likert-scale statements Q1, Q2 and Q4 but agreed to Liker-scale statement Q3 suggested ‘*To make it more readable and a more efficient design*’.

Some participants provided useful suggestions for future directions, which emerged as a main theme. Within this theme, the comments were categorised into two sub-themes, namely ‘Enhanced feedback for all the other questions’ and ‘New ideas for further improvement’. A few of the comments given in this theme are recorded in Table 10 in the Appendix, and one of these comments is as follows:

“I would also like to know the subject of each question so that I could Google anything that I didn't understand. Another option would be to have a link to the lectures that covered each question, so that if I got a question wrong I could know what lecture covered that topic.”

5. Discussion, conclusion and future work

This case study investigated how and to what extent the current enhanced feedback helps students to change their conceptual understanding and facilitate their understanding of the subject, together with their views on the user-friendly features and structure of the enhanced feedback. We were looking for students' views on the effectiveness of the enhanced feedback in correcting their misconceptions and improving their Engineering Mathematics learning. Further, we looked for their satisfaction of the user-friendly features in the enhanced feedback.

The results and the agreement percentages of the Likert-scale questions indicates that the majority of the participants agreed that the enhanced feedback improved their mathematical understanding and made them feel confident/comfortable with Engineering Mathematics. They also indicated that the information in the enhanced feedback is relevant to the question asked and that they are satisfied with the overall structure of the enhanced feedback.

The responses to the Likert-scale questions and the open-ended questions showed that the majority of the participants had positive feelings toward the enhanced feedback. Participants appreciated that the enhanced feedback helped them to address their misunderstanding and to improve their engineering mathematics learning.

The study also gave insight into how students find the user-friendly features of the enhanced feedback. Most of them had positive comments about its coherent structure and ergonomic features. One specific concern that emerged related to improving the visibility of the enhanced feedback. There were some very valuable suggestions of how to improve these features, such as moving it to a more noticeable place on the feedback report, and redesigning the enhanced feedback to have a more efficient and readable structure.

Some other notable suggestions were to include videos within the enhanced feedback and web links to extra materials. The majority of the participants highly valued the effectiveness of the enhanced feedback and suggested/wished to have enhanced feedback for the rest of the questions in the Engineering Mathematics e-assessments.

These suggestions and the highly positive perception of the enhanced feedback suggest that students find the enhanced feedback valuable for their learning. The positive responses on the CSE enhanced feedback have given us the encouragement to continue with the CSE project. We plan to continue our work by searching for further CSEs, providing enhanced feedback on questions delivered through the Dewis e-Assessment system and improving the layout of the enhanced feedback by taking some of the student suggestions on board.

6. Appendix

Table 3: Students' responses of Conceptual Change Theme for the question "*What do you like about the enhanced feedback you received?*"

Sub-Themes in Conceptual Change	Students' responses
Correct CSE capture (Correct capture)	*"Told me exactly where I went wrong."* *"It give me a good understanding of what I did."* *"It also explained in detail why I was incorrect."* *"The fact that the feedback tells me where I actually went wrong and if I repeat the test, then I would not make the same mistake."* *"The enhanced feedback got right to the reason the answer was wrong."* *"The Feedback which I received helped me to understand where I was most likely to make errors and showed the correct way of working out solutions."* *"I can clearly see where I went wrong and it gives me a chance to improve."* *"It helps me to make me realize the mistake where I went wrong on some type of questions."* *"It makes you feel conscious of errors you made. The fact that it tells you what you've done based on your final input is clever."* *"I think it is a great model of reinforcing problems of understanding."* *"It made me understand more in depth."*
Facilitate learning (Beneficial)	*"Very useful and well structured. Helps to answer any similar questions."* *"It was certainly useful to receive enhanced feedback alongside the standard feedback."* *"Very useful and helps to further understanding."* *"It helped my understanding."* *"I reckon that the enhanced feedback must be very helpful to those, who struggle with some questions."* *"I have read the feedback and it seemed very helpful and clear to me."*
Relevance of the content on CSEs enhanced feedback (Relevant).	*"Immediate and specific question related instead of a general explanation."* *"Its overall applicability to my work."* *"It's related to the problem."*

Table 4: Students’ responses of User-friendly Features Theme for the question “*What do you like about the enhanced feedback you received?*”

Sub-Themes in User-friendly Features	**Students’ responses**
Coherent structure	*“Very useful and well structured.”* *“The total feedback was overall concise”* *“Step by step method.”* *“It also explained in detail why I was incorrect.”* *“Short and simple.”* *“Clear and concise information.”* *“Well detailed with every step explained thoroughly.”* *“It shows the correct answer and detailed workings.”* *“Clear and concise.”* *“It’s very well structured so that it is easy to understand.”* *“Clear and concise method, made it easier to understand the question.”* *“Write all steps of solution.”* *“It’s well explained.”*
Accessibility	*“The total feedback was overall concise and accessible.”* *“Its simplicity.”* *“That it is instant.”* *“It was in a different colour so more visible.”* *“Immediate.”* *“Accessible feature and introduced to the user.”*

Table 5: Students’ responses of ‘Everything is alright’ Theme for the question “What do you dislike about the enhanced feedback you received?”

Main Themes	**Students’ responses**
Everything is alright/nothing to dislike	*“Nothing.”* *“There is not really much there to dislike, it's just maths feedback.”* *“Nothing to dislike.”* *“I haven't found any cons regarding the feedback.”* *“I find it good enough.”* *“No.”*

Table 6: Students’ responses of ‘Short Explanations Theme’ for the question “What do you dislike about the enhanced feedback you received?”

Main Theme	Students’ responses
Short Explanations	*“Some answers can be quite brief so more in depth answers would be great.”* *“Some feedback solutions explain steps without showing the working needed for those steps.”* *“Sometimes the workings are not easy to understand.”* *“Needs more steps for the student to fully understand what is happening throughout the equation.”* *“Sometimes it's unclear on how it gets from one step to another.”* *“For some questions it is really helpful. For other questions I don't think it goes far enough to explain the workings.”* *“I wish the enhanced feedback was more detailed.”*

Table 7: Students’ responses for ‘Less Accessibility Features Theme’ for the question “What do you dislike about the enhanced feedback you received?”

Main Theme	Students’ responses
Less Accessibility features	*“It was below the general feedback and correct answer, so it's easy to just scroll past.”* *“It's structure”* *“Needs to be more organised and easier to identify where you made the mistake.”* *“The incorrect answer could be written right after the correct one rather than right at the very bottom so that it would be easier to understand.”*

Table 8: Students’ responses of ‘Everything is alright’ Theme for the question “Do you have any suggestions for improvement?”

Main Themes	Students’ responses
Everything is alright/nothing to dislike	*“I think it is as good as it can be. Thank you!”* *“Nothing.”* *“It's good enough.”* *“No”* *“I think it is as good as it can be. Thank you!”*

Table 9: Students' responses of 'Suggestions to improve current features' Theme for the question "Do you have any suggestions for improvement?"

Sub-Themes	**Students' responses**
Detailed Explanations	*"Include all steps, even if they seem unimportant."* *"Make it a bit clearer to understand."* *"More detailed feedback, especially for integration and differentiation questions."* *"Highlight your mistake, but show other possible common mistakes optionally. That way you can roughly know what to look out for."* *"Include an extra example? Time consuming so understandable if not"*
More Accessibility features	*"To make it more readable and a more efficient design."* *"I would suggest using two columns when designing the layout for the feedback. One should just show my answer. The other shows the right answer with the detailed working."* *"Moving the incorrect answer closer to the correction or right next to it and maybe making it easier to find the questions you got wrong rather than scrolling all the way and having to search for it."*

Table 10: Students' responses of 'Suggestions for future directions' Theme for the question "Do you have any suggestions for improvement?"

Sub-Themes	**Students' responses**
Enhanced feedback for all the other questions	*"I would like more feedback for all question I get wrong, and with a more detailed step by step approach."* *"It doesn't give alternate answers with different questions as an option for more complex questions."* *"Not all questions has enhanced feedback."* *"I would prefer more feedback from Dewis, in particular more steps in how problems are solved."* *"Provide enhanced feedback not just on hard questions but on easy ones too."*
New ideas for further improvement	*"I would also like to know the subject of each question so that I could Google anything that I didn't understand."* *"Another option would be to have a link to the lectures that covered each question, so that if I got a question wrong I could know what lecture covered that topic."* *"Videos of a maths teacher doing each question and talking through each step."*

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CASE STUDY

Measuring the Success of Mathematics and Statistics Support Sessions at UWS

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Abstract

Following a review of the provision of mathematics and statistics support across Scottish Higher Education Institutions, academics at the University of the West of Scotland initiated weekly mathematics and statistics support sessions. These sessions were open to all students and staff across the institution, but primarily aimed at the science and engineering students with a high degree of numerate work in their study programmes. After two years of operation, previous attendees and students within key demographics were canvassed on their knowledge of, and opinion of, these support sessions. Four key points were uncovered: advertising of the existence of the sessions should be increased; the use of PhD students overseeing the sessions should be investigated; the centralisation of the sessions should be investigated; and more formal tutorial engagement should be encouraged.

Keywords: mathematics support, statistics support.

1. Introduction

Following a merger of the University of Paisley with Craigie College of Education in Ayr in 1993, Bell College in Hamilton in 2007, and several colleges of Nursing & Midwifery, the University of the West of Scotland (UWS) was established in 2007. With over 17,000 students, UWS is Scotland's largest modern University, with 130 EU partners and a growing number across the world, including links with over 40 institutions in China.

UWS provides a distinctive educational experience across five campuses in Ayr, Dumfries, Lanarkshire, Paisley, and London through a range of programmes, supported by strong applied research and knowledge transfer activities.

Situated in the Division of Physical Sciences, part of the School of Computing, Engineering, & Physical Sciences (CEPS), the Statistics, Operational Research and Mathematics Group (STORM) offers two degree programmes. Firstly, the B.Sc. in Mathematics with Education was validated in 2018. This saw its first intake for session 2019/20. Secondly, the B.Sc. in Mathematics was validated in early 2021, with a projected first intake in session 2021/22. Further, STORM provides teaching input into a large number of programmes within CEPS, and across the wider University. The main business of the group is within the Paisley campus, but it also provides input to programmes at the Ayr and Lanarkshire campuses.

As such, the group is faced with teaching mathematics and statistics to students who exhibit a wide range of mathematical interest and ability. Often, teaching approaches for science and engineering students are required to be modified, dependent on the particular student discipline (Jaworski *et al*. (2011), Learning and Teaching Support Network (2003), Shaw and Shaw (1999)). In addition, teaching approaches can sometimes change when considering the make-up of the cohort, e.g. considering cohorts with predominantly one gender (Achor and Ajai (2014), Dew *et al*. (1984), Haynes *et al*. (2004), Jameson (2020), Zettle and Raines (2000)).

Further, many students not on a mathematics degree programme *per se*, have shown signs of mathematical anxiety, a topic of continued discussion (Ashcraft (2002), Betz (1978), Dew *et al*. (1984), Haynes *et al.* (2004), Jameson (2020), Metje *et al*. (2007), Moodley (2011), Perry (2004), Zettle and Raines (2000)).

In 2017, one member of STORM, as part of the Scottish Mathematics Support Network, undertook an investigation of the provision of mathematics and statistics support across Scottish Higher Education Institutions (Ahmed *et al*. (2018)).

It was identified that UWS was the only Higher Education Institution in Scotland (specialised institutions, such as the Glasgow School of Art, aside) that did not provide a formal mechanism for mathematics/statistics support. In response to this, STORM set out to investigate the use and implementation of formal mathematics and statistics support at Higher Education Institutions across the world (Ahmed *et al*. (2018), Ahmed and Love (2010), Bailey *et al*. (2015), Breen *et al*. (2015), Clancy *et al*. (2015), Cronin *et al*. (2017), Curley and Meehan (2015), Gill *et al*. (2016), Lancaster *et al*. (2009), Lawson (2015), Lawson *et al*. (2012), Macdonald (2014), Matthews *et al*. (2013), Owen *et al*. (2011), Patel *et al*. (2010), Patel and Little (2006), Perkin and Croft (2011), Perkin *et al*. (2013), Pfeiffer *et al*. (2016), Samuels (2006), Samuels and Patel (2010), Symonds *et al*. (2008), Szatmari (2015), Tolley and Mackenzie (2015), van Veggel and Amory (2014)).

Following this investigation, in 2018, STORM established the “Mathematics and Statistics Support Clinic”, a weekly one-hour session, where at least one member of the group would be available to assist any UWS student (or, for that matter, any UWS academic) on mathematical or statistical matters.

As this resource was not centrally funded through staffing or resources, a classroom was booked at the same time on each teaching week of term (Wednesdays, 2pm-3pm), and advertised locally by “word of mouth” class announcements, followed up University-wide via banners on UWS webpages.

After two years of operation, the group has sought the views of students across the University on the success of the resource. Further, views on how best it might be improved have been sought.

2. Survey Design and Response Analysis

A survey (see Appendix) concerning, firstly, the awareness of, secondly the use of, and finally the success of the Mathematics and Statistics Support Clinics (hereinafter Support Clinics) was sent to every UWS student adhering to certain criteria.

The criteria specified any student who:

- was, or had been, in the last year, enrolled on a MATH-coded UWS module, or;
- was, or had been, in the last year, enrolled on a SPOR, BIOL, or CHEM-coded UWS module taught by a member of STORM, or;
- did not fall into the above two categories, but had visited the Support Clinic.

The entry criteria for the survey meant that around 400 students were sent an invitation to complete the survey. It would have been beneficial to STORM had this questionnaire been sent to the entire student body, so that the impact of University-wide banners advertising the Support Clinic could have been measured (as well as simultaneously promoting the Support Clinic). This will be considered for future analysis.

From the survey invitations sent, 47 responses were received, with the responses concerning the knowledge of and use of the Support Clinics detailed in Figure 1.

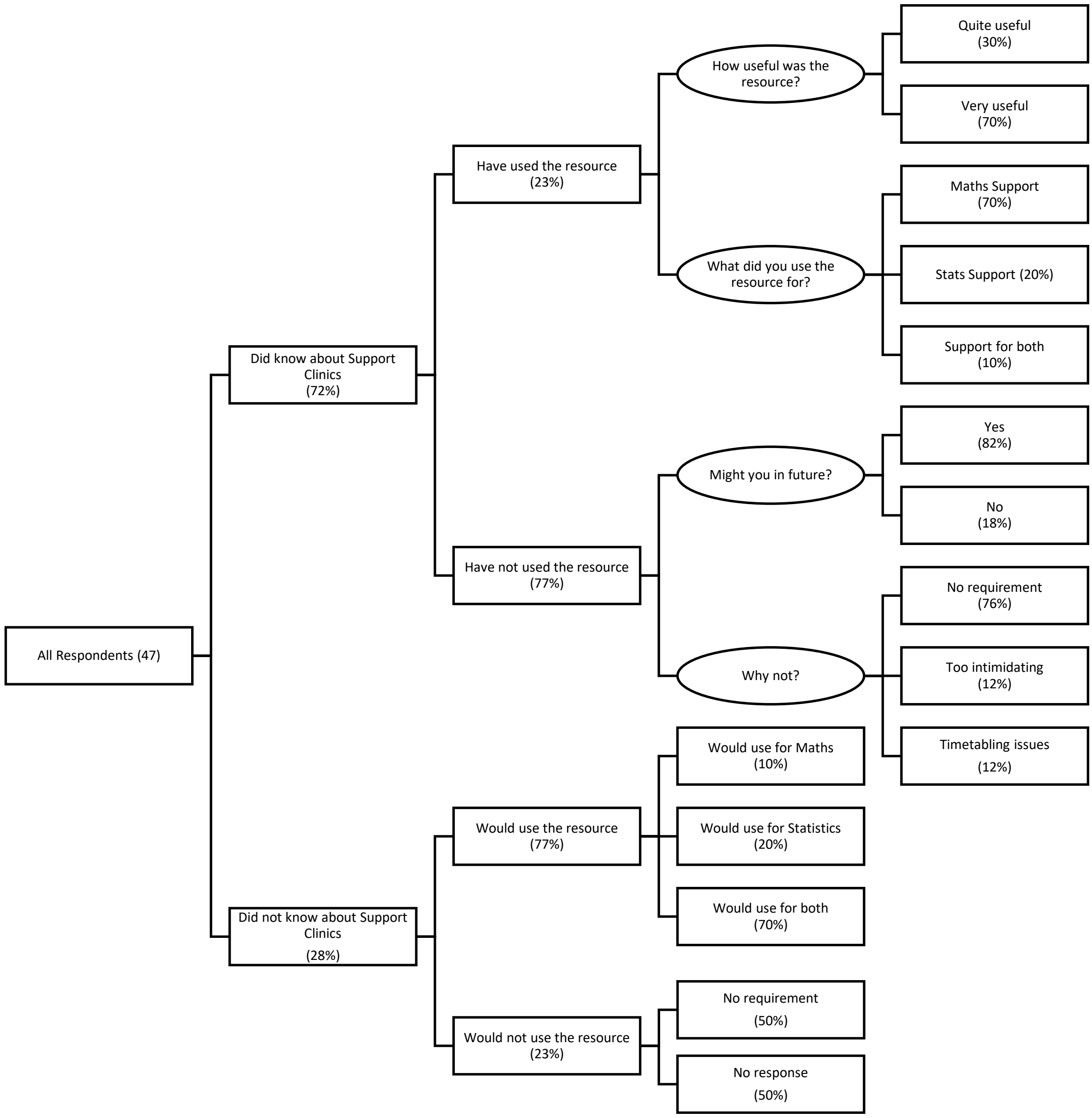

Figure 1. Flowchart of responses concerning knowledge of, and use of, Support Clinics.

Given that the students invited to respond either had been to a Support Clinic, or had been taught by a member of STORM (who are tasked with *ad hoc* advertising of the Support Clinics), it was disappointing to note that only 72% of respondents reported knowledge of the existence of the Support Clinics. Further, only 21% of respondents reported knowledge of the availability of dissertation and research project consultancy within the Support Clinic setting.

RECOMMENDED ACTION 1

To promote the Support Clinics both online (via the University VLE(s)) and in person.

We focus initially on those respondents who said that they had not heard of the Support Clinics. It was pleasing to see that 77% would use them now that this awareness was established. Most (70%) were willing to use the Support Clinics for both mathematics and statistics, 20% for statistics only, and 10% for mathematics only.

One of the inherent aims of the survey was to promote the Support Clinic, and this could be deemed to have been reached, albeit with the small numbers of students concerned. Of those students who would not use the Support Clinics, 50% felt that they had no need of them, and the other 50% failed to respond.

Of the students who had heard of the Support Clinics, only 23% had tapped into this resource. While this is disappointing at face value, 82% of respondents with this awareness did indicate that they would consider doing so in the future. The students who would not attend responded that this was the case because of “no requirement” (76%), “too intimidating” (12%), and “timetabling issues” (12%).

“*No requirement*”

This is self-explanatory.

“*Too intimidating*”

Raising the issue of an “intimidating” environment may arguably resonate with a level of mathematics anxiety within these students. They may be avoiding mathematics, and hence undercutting their mathematical competence (Ashcraft (2002)). Unfortunately, these are exactly the students for whom the Clinics are to cater.

A possible solution to this issue is to ask Ph.D. students to oversee Support Clinic sessions. However, this often introduces prohibitive pecuniary requirements. The authors suggest that the “intimidation” issue could be ameliorated were the Support Clinic organised, and operated, by a centralised support team, rather than the very same academics who teach the material that these students are finding difficult.

“*Timetabling Issues*”

The Support Clinics are timed in this Wednesday afternoon slot, when there should be no formal timetabled teaching events, and students are free to engage with extra-curricular activity, e.g. sports and societies. Being free of teaching events, this also allows STORM staff wider availability to support the Clinic sessions.

The authors are cognisant of the fact that “UWS continues to be Scotland’s leading University for Widening Access to students from disadvantaged backgrounds” (University of the West of Scotland (2019)), with almost a quarter of all SIMD 20* students in Scotland studying at UWS (Scottish Funding Council (2019)). Afternoons without scheduled teaching are often filled, therefore, with care duties, and part-time employment opportunities.

Unfortunately, STORM is unable to currently provide an alternatively timetabled, or additional, Support Clinic. While accepting that the Support Clinics do clash with other activities and arrangements, the timing is the “best case scenario” within the current University framework.

RECOMMENDED ACTION 2

To investigate the use of Ph.D. students in overseeing Support Clinic sessions.

RECOMMENDED ACTION 3

To investigate the centralisation of the Support Clinic, akin to most other support-providing institutions.

The survey goes on to question those students who had used the Support Clinics in the past. As we have seen earlier, 70% used them for mathematics support only, 20% for statistical support only, and the remainder for both. Consideration of this information should be combined with a realisation that the majority of STORM's teaching commitments are in mathematics. It is also noteworthy that both mathematics and statistics, especially the latter, is also taught by colleagues with STORM, and indeed CEPS.

Respondents who had used the Support Clinic were initially asked about the usefulness of the resource. A Likert scale was used, ranging from "not at all useful" to "very useful". 70% indicated the resource was "very useful" with the rest indicating it was "useful". STORM is pleased that to identify that here are no responses that suggest the activity was anything less than useful.

When questioned further, the results in Figure 2 were obtained. In addition to options A, B and C identified in the Venn diagram, respondents were invited to choose "Different Lecturer" or "Other" (via free text entry). These respondents selected neither of these options. The fact that the "Different Lecturer" option was not chosen might conceivably indicate that students who attend the clinics do not feel the environment is "intimidating". This contrasts with some responses from those who have not used the Clinics, as we have seen.

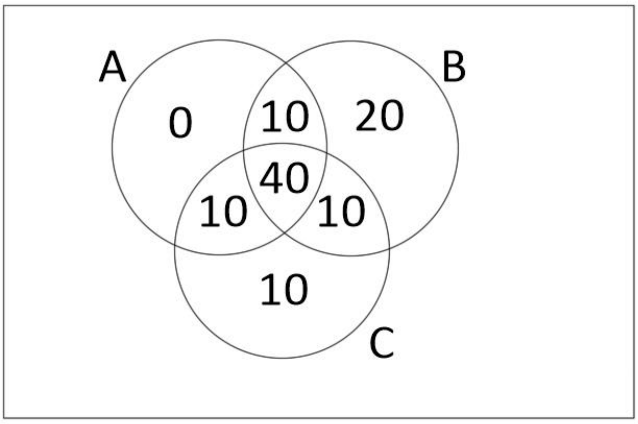

Figure 2. Venn diagram of responses concerning why Support Clinics are useful (by percentage), with A = One-to-one help, B = Questions to own specific questions, and C = Additional time.

To try to improve the resource, respondents who had previously attended were asked for their thoughts, with suggested responses via free text entry.

The results in Figure 3 were obtained, where the 40% outside sets A, B, and C in the Venn diagram represent "No improvements suggested". The majority of the other responses indicated the most apposite improvement was to extend the resource by running more Clinics. Again, this suggests evidence that having a centrally run support service may well be beneficial, with concomitant additions to the number of sessions made available.

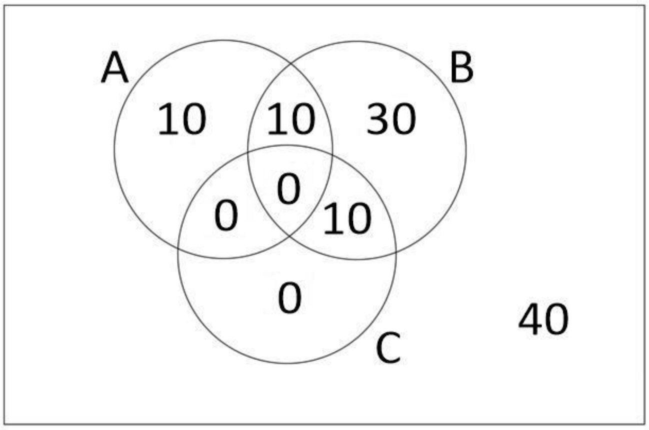

Figure 3. Venn diagram of responses concerning what can be done to improve the Support Clinics (by percentage), with A = Different Timetabling, B = More Clinics, and C = PhD students instead of academics.

The authors were interested in what alternatives would have been sought had no Support Clinics been available. Five possible responses were suggested, and the results of four of them are shown in the Venn diagram in Figure 4. The fifth option, “Nothing”, received no responses.

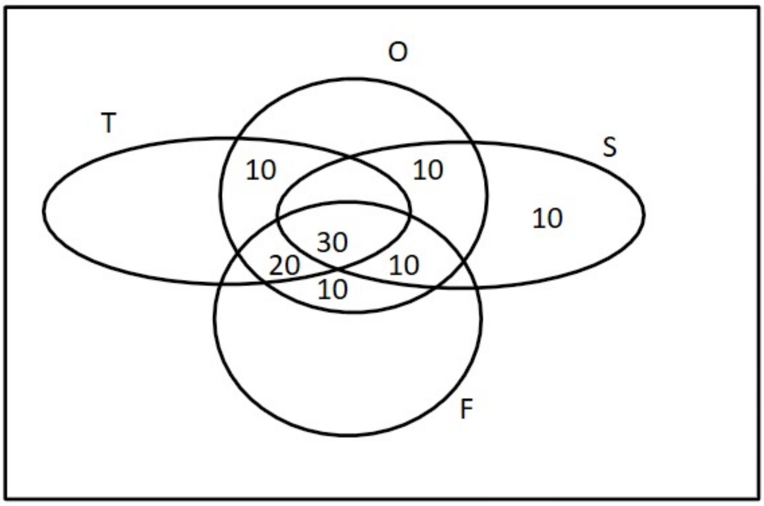

Figure 4. Venn diagram of responses concerning what students would do without the Support Clinics, with T = “Asked the Lecturer at a Tutorial”, O = “Asked the Lecturer at the Office”, F = “Asked a Friend” and S = “Worked on my Own”.

It is interesting to note that 90% of respondents would have sought out the lecturer at their office. Largely, STORM academics operate an “Open Door” policy, with no (within reason) set/restricted availability. Hence, it seems clear that, by having a dedicated time for support, STORM staff do not receive multiple ad hoc visits from students requesting support, potentially on the same subject material.

Further, as |S|=|T|= 60%, lower than |F|=70% and |O|= 90%, these students would rather seek help from a friend than try to work out their problems alone. Further, students would much rather ask a lecturer for help on a one-to-one basis at their office, instead of asking for help in a tutorial where other students would see that support is required.

It is encouraging to have some evidence that UWS students value peer support, and some degree of wider collegiality. On the other hand, resonating with the notion of “intimidating” environments, it is somewhat worrying that some students do not feel comfortable seeking support in tutorial sessions that they share with other students.

Such resistance to seeking support in tutorial sessions has a deleterious effect on their impact. Teaching staff may not be able to spot common issues among the cohort as quickly as would be liked. With the arrival of the pandemic and online lectures/tutorials in session 2020/21, this aspect has been exacerbated to an alarming degree. Informal feedback from colleagues in other disciplines in the University indicate similar levels of alarm.

RECOMMENDED ACTION 4

Encourage tutorial engagement among students.

Finally, students were asked for which modules they had sought support. Responses are given in Figure 5. Of the responses, 71% related to a MATH-coded module, which is taught by a member of STORM. Interestingly, 21% of responses were with respect to one such module that was taught solely to physics students. A further 21% of responses related to physics modules, with a high degree of mathematical content, which was not taught by a STORM member. It is perhaps plausible to infer that these students did see the benefit of the Support Clinic process across a range of modules. These figures can be compared and contrasted to the Support Clinic attendance records kept by the STORM group. In these records, each visit by each student is recorded, along with the corresponding class from which guidance is being sought. A summary of the last three years of data can be found in Figure 6.

We see from the figure that 64% of Support Clinic visits were concerned with a MATH-coded module. That is, a module delivered by a member of the STORM group. From this, 47% of visits were associated with mathematics, and 17% with statistics. What is interesting is that 15% of visits were associated with modules with a BIOL code (biology related module). Further analysis reveals that 8% were associated with a BIOL-coded module which was run by a member of STORM, and the remaining were visits from students requiring support in statistics to help with other modules from a different academic school (Health and Life Sciences). This figure also shows that 11% of Support Clinic visits were from students studying a CHEM-coded module (being related to either chemistry or forensic science), with 4% associated with an element of mathematics in a physical chemistry module (taught by a member of STORM) and the remaining concerning with statistics support in the final-year honours project. Finally, we note that 9% of visits to the Support Clinic were from students studying modules in (or researching in the fields of) business, computing, environmental science, health, physics, quality and project management, and sport science. All but the physics-related visits were concerned with support in statistics. This data does not agree with the response data as it shows that visits to the Support Clinic were almost equal in number in terms of mathematics and statistics support.

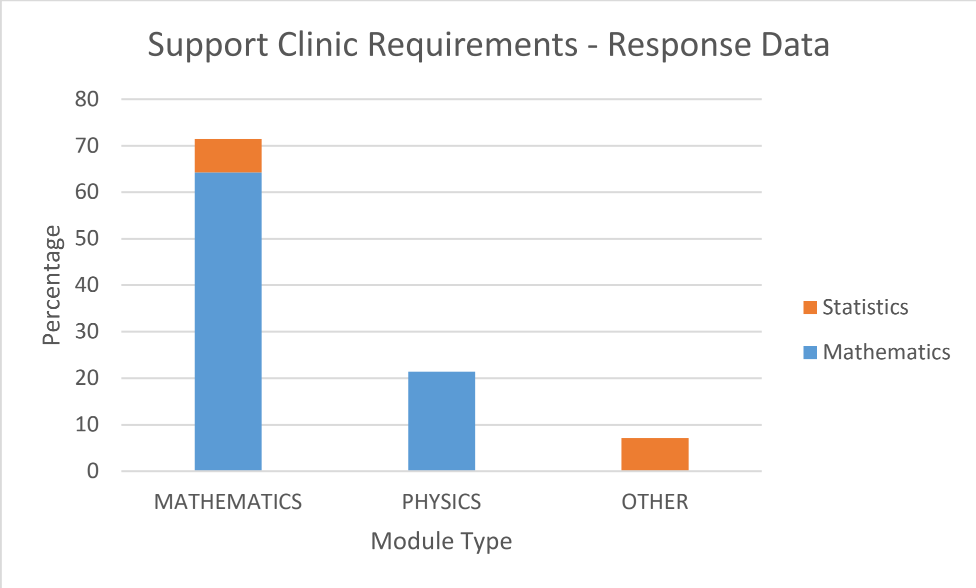

Figure 5. Percentage of visits to the Support Clinic in terms of module type (survey responses).

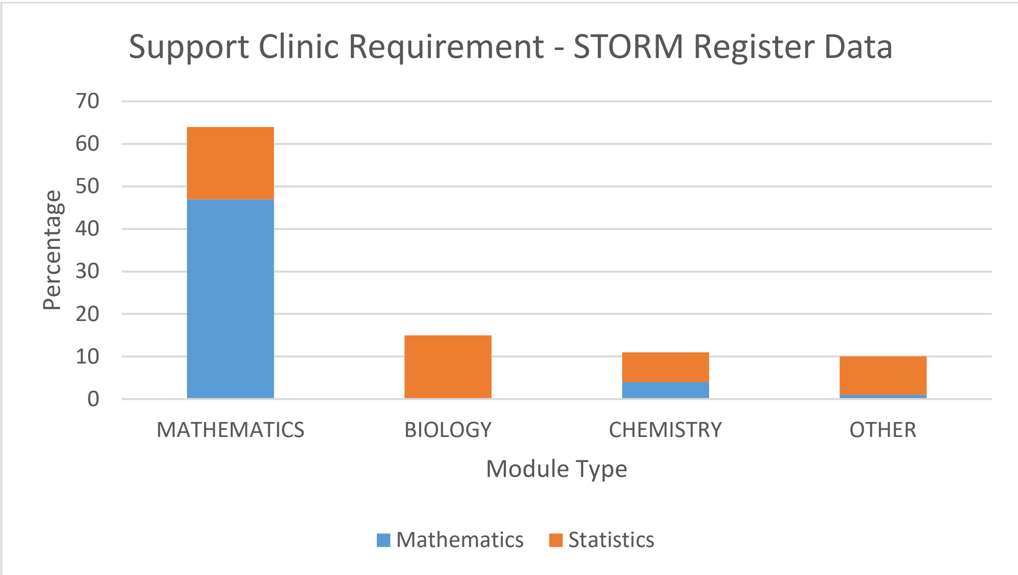

Figure 6. Percentage of visits to the Support Clinic in terms of module type (STORM attendance data).

Comparing Figures 5 and 6, we note that the response data is similar with regard to data concerned with MATHEMATICS-coded modules, but that the high response rate from physics students, in comparison to chemistry and biology students, seems to have created a mismatch between the response analysis and the attendance analysis. It is therefore clear that the earlier findings may be affected by a skew in the responses towards mathematics and physics students seeking assistance in mathematics.

3. Conclusions and Discussion

This paper has considered the operation and response to a new Mathematics and Statistics Support Clinic at the University of the West of Scotland. Around 400 students were sent a questionnaire concerning the knowledge of, use of, and perceived usefulness of the Support Clinic. A total of 47 responses were obtained.

Upon analysing the responses, it was clear that more work had to be done on advertising the Support Clinics, as only 72% of respondents reported an awareness of them. However, the authors were pleased to note that by simply asking about the Support Clinics, almost 80% of respondents reported that they would use them, now that they knew of their existence.

Two reasons given for not attending the Support Clinics were the intimidation factor, and the timetabling of the clinics. In order to address these factors, the authors will investigate centralising the Support Clinic, so that more sessions throughout the week can be offered, perhaps with the use of suitable Science and Engineering Ph.D. students.

One disappointing factor which emerged from the analysis was the fact that students seem unwilling to engage with lecturers during tutorial sessions. This will have a negative effect on uptake of knowledge and the authors will seek ways to encourage more engagement from students.

Finally, it is clear from comparing respondent data with attendance records that many cohorts of students (who have used the clinic) did not respond to the survey. This has meant that the conclusions and actions highlighted may be skewed towards mathematics support (particularly to students from our own school). Consequently, review of the large of amount of statistics support made available to students from disciplines such as chemistry, biology, health, and quality and project management has not been as fruitful as wished. In order to address this, the survey will be repeated each year over a period of five years. It is hoped that this data will provide opportunities for further analysis on the success of the Support Clinic as a whole, and on the year-on-year changes applied.

4. Appendix

1. Did you know that UWS offers Mathematics and Statistics Support Clinics?

   Yes ☐ No ☐
2. If your answer is No to Question 1: Now you know this exists, do you think you would use this resource?

   Yes ☐ No ☐
3. If your answer is No to Question 2, why not?

   Now go to Question 15.
4. If your answer is Yes to Question 2, would you attend for mathematics help, statistics help, or both?

   Mathematics ☐ Statistics ☐ Both ☐

   Now go to Question 15.
5. If your answer is Yes to Question 1, have you ever attended a Clinic?

   Yes ☐ No ☐
6. If your answer is No to Question 5, why is that the case?

   No need ☐ Too intimidating ☐ Poor timetabling ☐
7. Might you attend in future?

   Yes ☐ No ☐

   Now go to Question 15.

8. If your answer is Yes to Question 5, in what area did you require support?
   Mathematics ☐ Statistics ☐ Both ☐
9. How useful did you find the clinics you attended?
   Not at all useful ☐ Quite useful ☐ Very useful ☐
10. If you answered Quite or Very Useful in Question 9, what did you find useful?
    1-2-1 help ☐
    Additional time spent on subject ☐
    Different lecturer ☐
    Answers to my own specific questions ☐
    Other (please state)
    Now go to Question 12.
11. If you answered Not at all useful in Question 9, why?
12. What changes would you make that might improve the service?
    None ☐ Different timetabling ☐
    Different location ☐ Different lecturers ☐
    PhD students and not staff ☐ More clinics ☐
    Other (please state)
13. What would you have done without the Support Clinics?
    Asked a friend ☐ Worked on my own ☐
    Asked the lecturer at a tutorial ☐ Asked the lecturer at their office ☐
    Nothing ☐
14. For which module did you require help?
    MATH07001 Dealing with Data ☐ MATH07002 Sequences and Patterns ☐
    MATH07003 Space & Change ☐ MATH07005 Maths for Computing ☐
    MATH07006 Engineering Maths 1 ☐ MATH07007 Engineering Maths 2 ☐
    MATH07008 IT Skills & Math. Software ☐ MATH07009 Space & Change 2 ☐
    MATH08001 Mathematics for Design ☐
    MATH08002 Differential Equations ☐ MATH09002 Advanced Calculus ☐
    MATH09009 Complex Analysis ☐ MATH10001 PDEs ☐
    OTHER (Please state)
15. Do you know the clinic also offers mathematical and statistical consultancy for dissertation and research projects?
    Yes No

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RESEARCH ARTICLE

The effect of Kahoot on undergraduate student anxiety and confidence when studying statistics

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Abstract

Many undergraduate students are required to study statistics, but often struggle understanding concepts, lack engagement, lack confidence, or feel anxious about statistics. Kahoot is a game-based learning platform that can be used to increase student engagement and learning through real-time quizzes. This study aimed to evaluate the use of Kahoot on improving students' experience of studying statistics in an undergraduate (year 2) course. Pre and post Likert scale questionnaires (including the Statistical Anxiety Measure - SAM) were used to collect student responses about their statistics study experience. Questions related to anxiety, confidence, and for the post quiz, additional questions on the impact of Kahoot on behavioural engagement. Post survey results indicate positive changes in students' perceptions towards studying statistics in terms of anxiety and confidence. Kahoot was shown to have a significant and positive effect on student confidence and was also linked to lowered anxiety. Despite limited data, help-seeking anxiety explained over 50% of variation in final exam performance. Further research is recommended on the effect of Kahoot on student anxiety when studying statistics, particularly as it relates to confidence and performance.

Keywords: Confidence, statistics anxiety, Kahoot.

1. Introduction and Literature Review

Statistics is one of the most widely taught subjects in the undergraduate curriculum and contributes to the development of important skills such as problem solving, critical reasoning and decision making (Cui et al, 2019; Dempster & McCorry, 2009). However, for many students it is the most feared and disliked component of their studies and often seen as a necessity to progression which must be endured (Birenbaum & Eylath, 1994; Onwuegbuzie & Wilson, 2003; Ziedner, 1991; Nasser, 2004). In addition to the negativity surrounding the learning of statistics, it is thought that up to 80% of students suffer with situation specific statistics anxiety at some level (Onwuegbuzie & Wilson, 2003). It is well established in the literature that low self-efficacy towards learning statistics among students is generally associated with higher levels of experienced statistics anxiety (Chamberlain et al, 2015). Statistics anxiety has been linked to poor statistics assessment performance in numerous studies, but it is the link between statistics anxiety, student attitudes and negative learning behaviours which are thought to lead to poor performance (Macher et al, 2011; Gonzalez et al, 2016; Macher et al, 2013). Anxious students often try to avoid any statistical situation including not attending/listening to lectures, not asking for help, delaying work on assessments until the last minute, persevering less on tasks, and putting little effort into learning (Macher et al, 2011; Kesici et al, 2011), which can subsequently lead to poorer performance, reinforcing a student's view that they cannot do statistics.

Although suggestions for addressing anxiety have been made, very few researchers propose or evaluate strategies to reduce anxiety. Birenbaum & Eylath, (1994), Baloglu, (1999), Onwuegbuzie &

Wilson (2003), and Chew & Dillon, (2014) summarise strategies tested in the literature which are usually based on teaching strategies rather than behavioural strategies that students can implement. Examples include improving statistical textbooks (Johnston, 1977), using humour in the classroom (Schacht & Stewart, 1990), making more connections between concepts and real-life application (Ellman, 1991; Belli & Seaver, 1989), and using "sleuthing" stories upon which to practice statistical analyses (D'Andrea & Waters, 2002). Cohen (2014) discusses the importance of using games in the teaching of difficult subjects such as statistics, whilst Macheski et al. 2008 also highlight the importance of interactive classroom activities in creating a learning community and a safe, relaxed classroom environment. While there is little in the literature evaluating the use of games-based learning on either reducing statistics anxiety or increasing confidence, Schacht & Stewart (1990) hypothesise that interactive learning environments are important in the reduction of statistics anxiety.

The use of Audience Response Systems (ARS) for teaching statistics and mathematics subjects has been described previously. For example, Ramesh (2011) evaluated the use of an ARS in undergraduate statistics modules and found an improved learning experience, as evidenced by increased attendance and engagement. Rowlett (2010) recommends the use of ARS to facilitate more active learning, whilst Wit (2003) reported many positive impacts of using an ARS in a statistics class, including student enjoyment, and the ability for students to contribute without fear of making mistakes. Fullarton et al (n.d.) introduced arsnova-click: a gamified ARS for STEM (Science, Technology, Engineering, Mathematics) courses inspired by Kahoot and designed with a focus on privacy and anonymity.

Kahoot (https://kahoot.com/) is a game-based ARS and learning platform that can be used to increase student behavioural engagement and learning through real-time quizzes. Kahoot quizzes can be played either synchronously during a live class, or asynchronously if set for "Homework". Wang & Tahir (2020) carried out a review on the published effects of using Kahoot. Based on their findings, they concluded that Kahoot can have a positive effect on learning, classroom dynamics, motivation, concentration, and perceived learning by students. Of the 93 studies included in the review, 14 considered student anxiety, although none focused on statistics anxiety specifically. A concern of some teachers is that the use of Kahoot in the classroom may induce anxiety due to the focus on competition and time limits for answering quiz questions. However, 10 of the 14 articles reported a reduction in student anxiety (two of which included tests for statistical significance) due to factors such as facilitating more students to feel safe to participate and answer questions without fear of being judged, and the addition of humour. Only one study of the 14 reported that Kahoot could induce agitation (anxiety) (Moutinho & Sa, 2018). Interestingly, one study (Turan & Meral, 2018) compared Kahoot with another polling system Socrative (https://www.socrative.com/), and found there was a statistically significant difference in anxiety scores, where anxiety scores associated with Kahoot were lower.

The main aim of this study was to evaluate the impact of Kahoot on student reported levels of anxiety and confidence regarding statistics using pre-post surveys. For course students that completed both the pre and post surveys, the relationship between reduced anxiety/increased confidence and self-reported levels of behavioural engagement with lecture material was also explored. Another aim was to see if performance on the final exam was related to responses in the post survey.

2. Method

2.1. Participants

The participants of this study were undergraduate students enrolled in the second-year course *Practice of Science* in Semester 1 of 2020. Most students (68%) were enrolled in biology-based degrees, with approximately 50% of students enrolling in *Practice of Science* as a core course for their degree or major. The remaining students chose it as an elective or as a prerequisite for a third-year course. All 129 students enrolled in *Practice of Science* were invited to take part in the study and participation was voluntary.

2.2. Course background

This course was established in 2013 by the School of Life Sciences to provide biology students with a second-year course that encompassed experimental design and statistical concepts. The need for statistics in second year biology was identified by 3rd year biology course coordinators who felt students had either not retained first year statistical knowledge or missed statistics prior to third year. In particular, many students did not appear confident in determining the correct statistical test to use with data collected in the field or lab. Practice of Science has always been co-taught by two different departments. Over the years the lecturing staff have changed but since 2014 one of the authors (PH) has been involved to different extents in the experimental design component of the subject and since 2019 another author (AS) has lectured for the statistics component. In 2020 there was a single lecturer for each component (AS for statistics and PH for experimental design), with corresponding teams of teaching assistants for weekly workshops.

One challenge for this course has been the successful integration of the two components so that students do not perceive each as stand alone and see the link to their biology studies. Over the last two years AS and PH have ensured use of the same terms where there may be differences, referred to each other's lectures where applicable, and have carefully considered the sequence of learning activities and assessments. Another challenge has been delivering the statistics component to a cohort of students with a diverse range of backgrounds in quantitative skills. Some students have not studied any maths since aged 16 at secondary school, while others have first year undergraduate maths or statistics. In addition, instruction on using the statistical package SPSS is given, which some students had not encountered previously.

Assessment of experimental design concepts includes a group oral presentation, online quizzes, an ongoing group task (3-4 students per group) of designing a hypothetical experiment but with individual submission of a written summary, and half of the end of semester exam. The statistics component (termed data analysis in the course notes) is assessed via online quizzes, two assignments, and half of the end of semester exam. Linking of the two components is achieved as students are required to state the statistical test they would use for the data in their proposed experiment study and why. To lessen student anxiety around missing an online quiz and to minimize course coordinator administration regarding missed quizzes, the best five marks of the seven online quizzes was used towards a student's final grade. PH has successfully used this 'best of' approach in other subjects and gives students an element of 'choice', which may encourage a more active role in learning (Nicol, 2009) and reduce stress about the assessment (Cook, 2001).

Kahoot was typically used at the end of each statistics lecture whereby four to six multiple choice questions were asked so that students could check their comprehension of the material in that lecture. The statistics lectures were delivered face-to-face for one week at the beginning of the semester. At that point, due to COVID-19 and the associated lockdown in Melbourne, Australia, the remaining lectures were delivered asynchronously through the use of pre-recorded videos. As such, the Kahoot quizzes were adapted to also be administered asynchronously so that students could play the Kahoot game in their own time after having watched the associated lecture material. Engagement with the lecture material and the Kahoot quizzes remained similar with this format as had been seen in previous years with a fully face-to-face format. During the final week of the semester, a longer 'revision Kahoot', which included questions relating to data analysis topics throughout the semester, was administered live over Zoom. In general, although not assessed, the

Kahoot quizzes were useful practice for the assessed online quizzes which were related to the corresponding week of statistics material.

2.3. Data collection

A pre-post research design was used to measure confidence and anxiety levels experienced by students at the beginning and end of the semester respectively. The post survey also included questions regarding students' perceptions of the effect of Kahoot. In addition, responses from the pre and post surveys were matched to data available from the Learning Management System including student performance. Ethical approval to carry out the research study was obtained from the university human ethics research committee.

Several subscales measuring different aspects of statistics anxiety were taken or adapted from the Statistical Anxiety Measure - SAM (Earp, 2007) and the Statistical Anxiety Rating Scale - STARS (Cruise, Cash and Bolton, 1985). Details of the items for each subscale for task anxiety (SAM, 8 items), anxiety about asking for help (STARS, 3 items) and software anxiety (adapted, 3 items) are included in the Appendix with Cronbach's alpha values. Anxiety about choosing the right technique was analysed separately. Each question asked how anxious students felt in different situations on a 7 point scale from Not at all anxious (1) to Extremely anxious (7). Confidence was also measured using 4 items (alpha = 0.89), each measured on a 7-point scale from Strongly disagree (1) to Strongly agree (7) of feeling confident with choosing the right statistical test, statistical software, interpreting output, and writing a statistical report. The same questions were asked in the post survey with the addition of questions specifically asking about the impact of Kahoot on their learning, and motivation to engage.

To better understand whether changes in anxiety and confidence during the year could be directly linked to the use of Kahoot, additional questions were included in the end of semester survey, asking students to think about the impact of Kahoot on anxiety and confidence when first going through the lecture material and studying statistics generally. In each scenario, 5-point Likert scales ranging from 1A lot less anxious (1) to A lot more anxious (5) for anxiety and A lot less confident (1) to A lot more confident (5) for changes in confidence due to Kahoot. For these additional questions, a 5-point scale was more suitable than a 7-point scale when considering the possible categories available in the question (see Appendices 6.1 and 6.2).

Of the 129 students who were enrolled in and completed the subject, the pre and post surveys were completed by $n = 20$ and $n = 9$ students respectively, and 5 of those students completed both the pre and post surveys. For students who completed both the pre and post surveys, the course final exam mark for the Data Analysis section was retrieved after students had received their final grade for the course.

2.4. Data analysis

Descriptive statistics were used to present overall mean pre and post anxiety and confidence scores and student responses regarding the effect of Kahoot on anxiety and confidence. The paired *t*-test was used to test whether mean changes between pre and post scores of the summary anxiety and confidence measures were significant. The Normality assumption was checked using Normal Q-Q plots and the Shapiro-Wilk test, and we note that the *t*-test has been shown to be valid even for extremely small sample sizes of $n \leq 5$ (de Winter, 2013). The Wilcoxon signed-ranked test was used to test whether the changes between pre and post anxiety and confidence scores of the single item regarding *choosing the right statistical test* was significant. Effect sizes were provided to measure the relative size of the changes. The Wilcoxon signed-ranked test was used to test for statistical significance of the impact of Kahoot on student learning, motivation to engage, anxiety, and confidence with statistics. The Spearman correlation coefficient was used to measure the strength of association between the reported impact of Kahoot on student learning, and the reported impact of Kahoot on anxiety and confidence. Linear regression was used to measure the association between student performance and statistics-related anxiety, with assumptions checked via a scatterplot of the data, and residuals versus fits and Normal Q-Q plots. Statistical analyses were carried out using R version 4.1.1 (R core team, 2019).

3. Results

Prior to specifically examining the effect of Kahoot (Section 3.2), the pre and post anxiety and confidence data is explored (Section 3.1). Next, the relationship between behavioural engagement measures and student perception of benefit to learning is examined (Section 3.3). Lastly, how measures of anxiety, confidence, and impact of Kahoot related to student performance is described (Section 3.4).

3.1. Overall student anxiety and confidence levels

Figure 1 shows the mean pre and post anxiety scores and the mean pre and post confidence scores, with error bars representing 95% confidence intervals also shown. Based on the n = 20 and n = 9 students who completed the pre and post surveys respectively, all mean anxiety scores showed a decrease between the two surveys, while all mean confidence scores showed an increase between the two surveys. The largest observed difference between pre and post scores for both confidence and anxiety was for choosing the right statistical test.

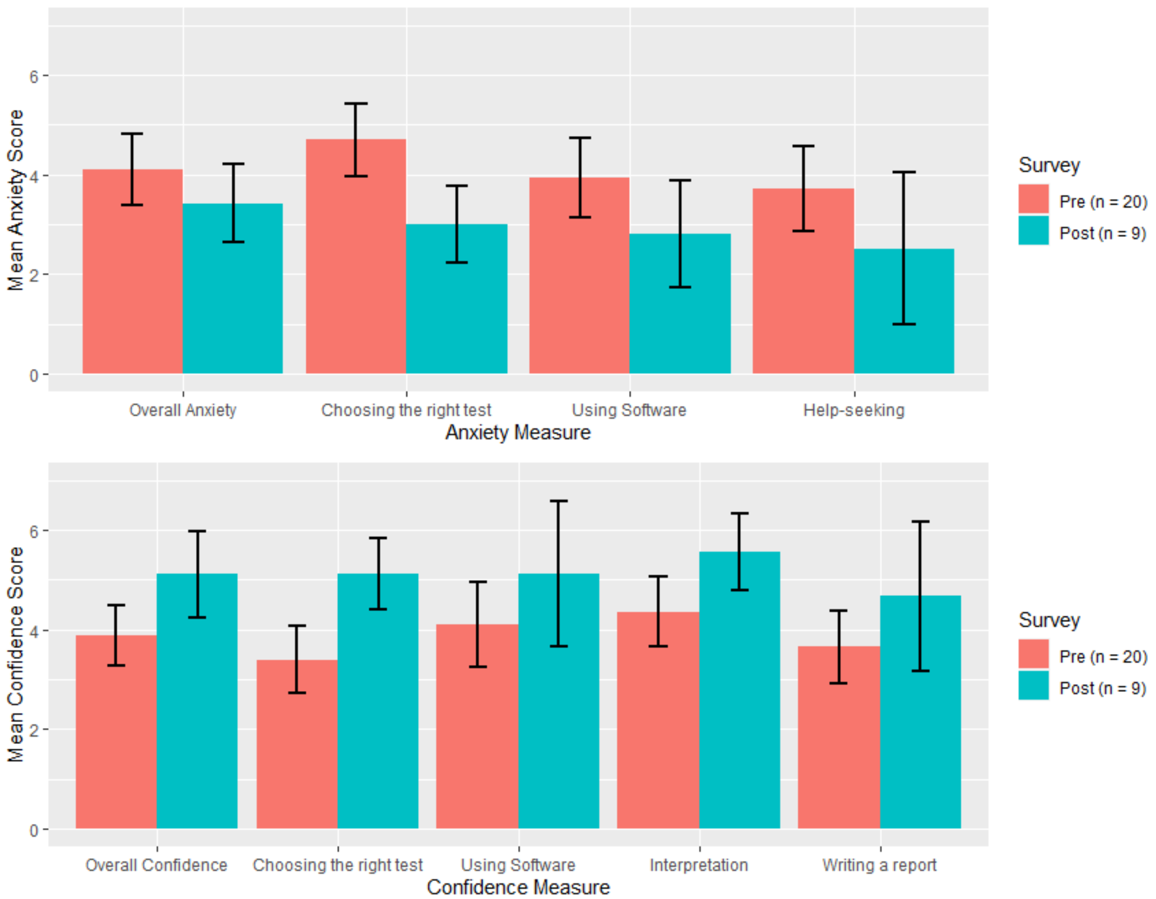

Figure 2. Mean pre and post anxiety scores (top) and confidence scores (bottom) with error bars representing 95% confidence intervals shown.

To assess which changes were statistically significant, only the responses of the five students who completed both the pre and post survey could be used. Table 1 shows the results (*p*-values) of the paired *t*-test, standard error, mean change, and effect size of anxiety related to using software and help-seeking, as well as the overall confidence and anxiety measures. The remaining measures listed in Figure 1 were not appropriate for a *t*-test analysis (non-Normal) and are therefore not included in Table 1. Significant results ($p < .05$) and large effect sizes ($d \geq 0.8$) are highlighted in bold. The results indicate that, on average, the reduction in average anxiety levels based on the SAM and help-seeking anxiety measures was statistically significant. The effect size (standardised mean change) was large for all measures in Table 1 except for the Software anxiety measure, for which the measured change was zero.

Table 1. Results of paired *t*-tests (n = 5) for significant changes between pre and post anxiety and confidence measures, along with mean change and effect sizes. Significant *p*-values and large effect sizes are highlighted in bold.

Measure	Mean change *(Effect size)*	Std. Error	p-value
Anxiety about using software	0.000 *(0.00)*	0.723	1.00
Anxiety about help-seeking	-0.867 ***(-1.25)***	0.309	**0.049**
Overall statistical anxiety measure	-0.425 ***(-1.26)***	0.151	**0.048**
Overall confidence measure	0.900 ***(0.88)***	0.458	0.12

To assess the statistical significance of the changes in anxiety and confidence with regard to choosing the right test, the Wilcoxon signed-rank test was carried out. This was an important item within the context of the Practice of Science course, because developing the skill of choosing the correct statistical test is one of the main intended learning outcomes of the course. Associated Wilcoxon effect sizes were calculated where possible effect sizes can vary from $r = 0$ to 1, with an effect size of 0.5 or more considered large (Tomczak and Tomczak, 2014). The results indicated that the change in anxiety was statistically non-significant ($p = 0.18$), although the effect size was large ($r = 0.76$). The change in confidence was close-to-significant ($p = 0.057$) and the effect size was large ($r = 0.91$). Considering the small sample size (n = 5), these results are encouraging and indicate that by the end of the course, students seemed to become more confident and less anxious regarding choosing the correct statistical test. This indicates that consideration of these items in a larger study would be beneficial.

3.2. Impact of Kahoot on student confidence and anxiety

To assess the impact of Kahoot on student confidence and anxiety, at the end of semester students were asked to indicate how their confidence and anxiety was affected due to the use of Kahoot, with regard to going through the lecture material for each topic, and studying statistics generally. The impact on confidence and anxiety was measured on a 5-point likert scale. The results are shown in Figure 2, which includes the responses of the n = 9 students who completed the post survey. With regard to anxiety related to both items, almost all students reported either no change (yellow) or less anxiety (green). One student reported more anxiety (orange). With regard to confidence related to both items, most students reported an increase in confidence due to the use of Kahoot, with either 1 or 2 students reporting no change, and one student reporting a decrease in confidence.

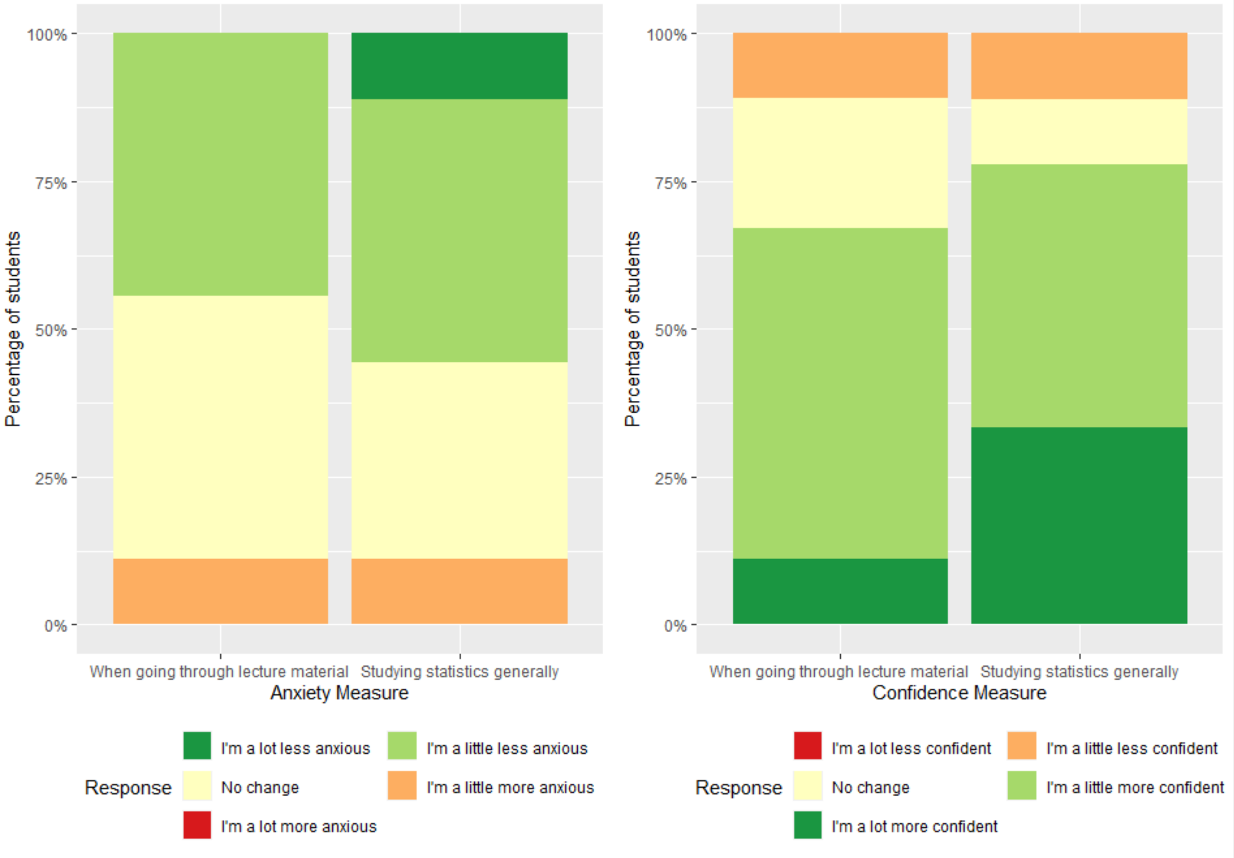

Figure 3. Student responses regarding the effect of Kahoot on anxiety (left) and confidence (right). Positive impact (less anxious or more confident) represented by green colours.

Willcoxon signed-rank tests were carried out to test the reported impact of Kahoot on student confidence and anxiety, testing whether the true median is different from 3 (no change). The results for these tests based on the n = 9 responses are shown in Table 2, which shows *p*-values, estimated median values, and effect sizes. Significant results ($p < .05$) and large effect sizes ($r \geq 0.5$) are highlighted in bold. Students reported that Kahoot had a positive, large and statistically significant impact on their confidence studying statistics generally, and a positive, large and close-to-significant impact on their confidence when first going through the lecture material for each topic. The reductions in anxiety as a result of Kahoot were not statistically significant, however the effect size for studying statistics generally was large ($r = 0.56$), and moderate ($r = 0.45$) for going through the lecture material for each topic. Again, considering the small sample size (n = 9), these results are encouraging and indicate that Kahoot can have a positive effect in terms of student confidence and anxiety while studying statistics. This indicates a larger study considering these effects would be of benefit.

Table 2. Results of Wilcoxon signed-rank tests (n = 9) for whether the true median effect of Kahoot on anxiety and confidence measures is different from 3 (no change). Median values and effect sizes are displayed. Significant *p*-values and large effect sizes are highlighted in bold.

Question	Anxiety 1 = I'm a lot less anxious, 5 = I'm a lot more anxious		Confidence 1 = I'm a lot less confident, 5 = I'm a lot more confident	
	Median value *(Effect size)*	p-value	Median value *(Effect size)*	p-value
When first going through the lecture material for each topic	3 *(0.45)*	0.23	4 ***(0.638)***	0.071
Studying statistics in this subject generally	2 ***(0.56)***	0.12	4 ***(0.728)***	**0.036**

3.3. The relationship between Kahoot's impact on learning and engagement, and its impact on statistics anxiety and confidence

In addition to the questions asking about the impact of Kahoot on anxiety and confidence, two questions were added to the 7-point agreement scale questions in the post survey. The items were *Kahoot helped motivate me to engage more with the lecture content* and *Kahoot worked well in helping me learn* (see Appendix 6.3). Willcoxon signed-rank tests were carried out to test the reported impact of Kahoot on motivation to engage and learning, testing whether the true median is different from 4. Associated Wilcoxon effect sizes were calculated where possible effect sizes can vary from $r = 0$ to 1, with an effect size of 0.5 or more considered large (Tomczak and Tomczak, 2014). The n = 9 students who completed the post survey reported that Kahoot had a positive, large, and close-to-significant impact on engagement with lecture content ($p = 0.10$, $r = 0.56$) and learning ($p = 0.093$, $r = 0.58$), with a median score of 6 for both measures. An analysis of the Spearman correlation between these two items yielded some interesting results. In particular, there was a perfect and highly significant correlation (1, $p < .001$) between the agreement scores of these items. This would seem to indicate that student behavioural engagement and student perception of learning are linked.

Also of interest was the observed relationship between the item *Kahoot worked well in helping me learn* (and by default *Kahoot helped motivate me to engage more with the lecture content*) and the effect of Kahoot on anxiety and confidence. The sample Spearman correlations are provided in Table 3, which shows significant, strong, negative associations between the impact of Kahoot on learning and on anxiety, and highly significant, very strong, positive associations between the impact of Kahoot on learning and on confidence. Recalling the results in the previous section, the effect of Kahoot on anxiety was not significant. However, the impact of Kahoot on items related to confidence and perceived learning were all positive and either significant or close-to-significant. The highly significant and strong, positive associations between the reported effect of Kahoot on student learning and confidence shown in Table 3 therefore indicate that Kahoot has had a positive impact on perceived student confidence and student learning overall, although the presence and direction of causation is unclear.

Table 3. Sample Spearman correlations between the reported impact of Kahoot on learning, and the reported impact of Kahoot on measures relating to anxiety and confidence.

	Reported impact of Kahoot on anxiety		Reported impact of Kahoot on confidence	
	When going through the lecture material for each topic	Studying statistics in this subject generally	When going through the lecture material for each topic	Studying statistics in this subject generally
Kahoot worked well in helping me learn	-0.75*	-0.64.	0.82**	0.88***

p-values (0, 0.001, 0.01, 0.05, 0.1, 1) <=> symbols("***". "**", "*", ".", " ")

3.4. Relationship to student performance

Linear regression modelling was carried out to assess the relationship between student performance on the exam, and all items related to anxiety, confidence and the impact of Kahoot. Most items were not found to be significantly associated with student performance, although this may be partially due to the limitation of a small sample size (n = 9). However, despite the small sample size, anxiety associated with asking for help was significantly associated with student performance based on responses from both the pre and post surveys. The result from the post survey data is reported here: in particular, a simple linear regression analysis was conducted to test the association between exam mark as the response, and the anxiety measure for *Asking one of my statistics teaching staff for help in understanding computer output* as the predictor. The results of the regression indicated that help-seeking anxiety explained 52.39% of the variation in exam marks (R^2 = .5239, F(1,7) = 7.704, p = .028). Help-seeking anxiety score is a significant predictor of exam mark (β = -3.683, p = .028). For each additional point in help-seeking anxiety score, on average, exam mark was between 0.55 and 6.82 marks lower. This finding indicates that help-seeking anxiety and ways it can be addressed warrants further research.

4. Discussion, conclusions, and future work

The results indicate positive, large, and some significant (or close-to-significant) changes in both student confidence and statistics-related anxiety when comparing pre and post scores. The results further indicate that Kahoot can have a positive impact on student confidence and student engagement & learning, and further that the impact of Kahoot on these aspects are correlated. Although the effect of Kahoot on anxiety was positive, the results were not as strong as the effect of Kahoot on confidence. Considering possible reasons for this, anecdotal evidence suggests that timed testing can be anxiety-inducing or affect performance for some students [this has also been seen in the literature; e.g. Onwuegbuzie & Seaman (1995)], but that this may not necessarily inhibit increases in confidence. For instance, consider one student's response in the post survey to the question, *What else (if anything) has helped reduce your anxiety about studying statistics this semester?:* "Most of my anxiety is around timed testing…". This student also responded that Kahoot had a positive impact on motivation to engage, learning, and confidence, but no change to anxiety. Although the negative association between statistics anxiety and student performance is documented in the literature (Chew & Dillon, 2014), Keeley et al., (2008) found that very high or very low levels of anxiety were associated with lower performance, while mid-range anxiety was associated with higher performance. They argued against assuming that lengths should be taken to eliminate all anxiety, while Onwuegbuzie & Wilson (2003) suggested that some statistics anxiety can even be facilitative rather than debilitative when not experienced in extreme measures. Hence, it may be argued that some anxiety may be acceptable when associated with playing Kahoot, particularly if at the same time it is a confidence-building exercise that facilitates better learning.

Still, Wang & Tahir (2020) summarise some useful suggestions that can help to reduce student anxiety, one of which is that students can be anonymous while playing Kahoot by using nicknames, which can lead to reduced stress and creation of a safer environment within which to fail. To reduce the potential fear of losing Kahoot games, Wang & Tahir (2020) report that playing Kahoot as teams rather than individuals has been suggested. Another obvious suggestion for the anxiety some students experience around pressure to answer questions quickly is to increase the time allowed to answer questions, although this may not always be possible within the time constraints of a class. At present, the possible time that can be allowed for answering a question ranges from 5 seconds to 4 minutes. Verbal feedback from students about the assessed online quizzes indicated that students greatly appreciated the long timeframe (2 hours) within which to complete them, perceived that they were helpful for learning, and were useful for staying on track with course content; observations which warrant further research into the use of online quizzes to facilitate learning and reduce statistics anxiety.

The obvious association observed between anxiety related to help-seeking and student performance is an observation that also warrants further investigation. These preliminary results indicate that a future workshop based on statistics-related anxiety (see, e.g. Marshall et al, 2017), with a particular focus on the benefits of help-seeking, along with strategies to normalise help-seeking in the curriculum, may have a positive impact on student performance.

A limitation of this study is the limited sample size and associated low response rate, which may have increased the risk of self-selection bias. Still, this study has led to some interesting observations that warrant further investigation. Recommendations for further research are therefore as follows:

1. A repeat of this study but with a higher sample size, so that findings can be generalised with greater certainty;
2. Research into the reasons why Kahoot helped increase confidence or reduce anxiety, where this has occurred;
3. A study on statistics anxiety workshops that have a particular focus on help-seeking, along with strategies in the curriculum to encourage and normalise help seeking, including measurement of the impact on student performance;
4. A study on online tests with generous time-limits that can be repeated as a confidence-building strategy, measuring the impact on anxiety, confidence, and performance.

5. Acknowledgements

The authors wish to thank the editor and referees, whose valuable comments led to an improved version of this article.

6. Appendix

6.1. Statistics anxiety scales

All statistics anxiety measures contained items asking how anxious students felt in the specific situation from 1 (Not at all anxious) to 7 (Extremely anxious). The same scales were used in the pre and post surveys.

Scale and Cronbach's alpha (post survey)	Individual items
	Statistical task anxiety
Statistical anxiety measure (Earp, 2007) **Cronbach's alpha = 0.94**	Sitting an exam in person on campus
	Studying statistics generally
	Reading statistical studies
	Calculating probabilities
	Formulating and testing hypotheses
	Developing conclusions based on mathematical solutions
	Interpreting statistics
	Explaining your statistical findings
	Software anxiety
Created by Marshall as existing scales do not contain items relating to software Cronbach's alpha = 0.89	Inputting/manipulating data in statistical software
	Using statistical software to carry out analyses
	Summarising results from the statistical software output
	Fear of asking for help
Statistical Anxiety Rating Scale - STARS (Cruise, Cash and Bolton, 1985) Cronbach's alpha = 0.9	Going to my statistics lecturer for individual help with material I am having difficulty understanding
	Asking a statistics lecturer for help understanding computer output
	Asking a fellow student for help in understanding statistics material

In order to ascertain whether changes in anxiety related specifically to the use of Kahoot, some additional questions were added to the post survey.

How has using Kahoot in this subject impacted on any anxiety you may have had about Statistics?	I'm a lot less anxious	I'm a little less anxious	No change	I'm a little more anxious	I'm a lot more anxious
When first going through the lecture material for each topic					
Studying statistics in this subject generally					

6.2. Statistics confidence scales

Students were asked how much they agreed with the following questions about confidence with key aspects of statistics on a 7 point scale from 1 (Strongly disagree) to 7 (Strongly agree).

Statistical confidence **Cronbach's alpha = 0.89**	I feel confident choosing the right statistical test
	I feel confident interpreting results from statistical software
	I feel confident using the statistical software taught on my course
	I feel confident writing a statistical report

In order to ascertain whether changes in confidence related specifically to the use of Kahoot, some additional questions were added to the post survey.

How has using Kahoot in this subject impacted on any confidence you may have had about Statistics?	I'm a lot less confident	I'm a little less confident	No change	I'm a little more confident	I'm a lot more confident
When first going through the lecture material for each topic					
Studying statistics in this subject generally					

6.3. Additional questions measuring impact of Kahoot

Students were asked in the post survey how much they agreed with the following questions about the impact of Kahoot on a 7 point scale from 1 (Strongly disagree) to 7 (Strongly agree).

Engagement and learning	Kahoot helped motivate me to engage more with the lecture content
	Kahoot worked well in helping me learn

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RESEARCH ARTICLE

Topics of interest to the MSOR community: evidence from the first 20 years of MSOR Connections

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Abstract

Topic modelling, an automated literature review technique, is used to generate a list of topics from the text of all articles published in previous issues of *MSOR Connections*. There are many topics of consistent popularity, including assessment, employability, school-university transition and the teaching of specific subjects and skills with the mathematics, statistics and operational research disciplines. We identify some topics that have waned in popularity, especially following the demise of the MSOR Network, including organised book and software reviews, conference and workshop announcements and reports, and articles focused on staff development. In its present form as a fully peer-reviewed practitioner journal, there appears to be a shift in focus from personal reflection to evidence-based research. There is a high focus on innovative practice using technology in the publication, though with less focus on specific software over time. Similarly, more nuance appears to be entering the discourse over maths support and e-assessment as these topics mature. We note a rise over time in student-centred approaches and a sudden rise in the previous issue of digital and remote learning due to the COVID-19 pandemic. We speculate about future trends that may emerge, including an increased focus on digital and remote learning and an increase in content on equity, equality, diversity and inclusion.

Keywords: Topic modelling, review, history of mathematics education.

1. Introduction

The first issue of *MSOR Connections* was published in February 2001, and the most recent issue was published in January 2021. This means the 62 issues published prior to the current one span a 20 year period. Recently, we have been impressed by insights into mathematics education research papers using a method called topic modelling (Inglis and Foster, 2018; Marks et al., 2021), which attempts to determine key topics from a large corpus of documents. This 20th anniversary of *MSOR Connections* seems an ideal time to apply this method to the archive of articles published in this journal, in hopes of identifying for the benefit of the community the topics which are discussed in *MSOR Connections* and changes over time in their popularity. By highlighting what we as a community have been talking about, we hope we might provide a prompt for reflection by future authors in the journal about topics either commonly studied or under-studied.

2. Background

In 2000, the Learning and Teaching Support Network (LTSN) established a series of 24 subject centres aiming to collect and share “good practice, experience and innovation in a coherent and accessible form” (Allan, 2000). One of these centres was the Maths, Stats and OR (MSOR) Network, comprising elements of the previous Computers in Teaching Initiative centres in mathematics and statistics and linked to the RSS Centre for Statistical Education (Blake, Davies and Bishop, 2000). The new subject centre established a newsletter called *Maths, Stats & OR*, which published four issues in 2000 before being relaunched as *MSOR Connections* with volume 1 issue 1 published in

February 2001 and each volume covering a calendar year thereafter. (Thus the MSOR *Network* had its *Connections*, a serviceable pun somewhat lost on new readers nowadays!) Volumes 1-9 contained four issues, volumes 10-11 contained three issues and volume 12 contained two issues. *MSOR Connections* served as the newsletter of the MSOR Network and also as a practitioner journal for the community it served. The MSOR Network and *MSOR Connections* survived the incorporation of LTSN into the new Higher Education Academy (HEA) in 2004 (Blake, 2004), and continued until the HEA closed the subject centres in 2012 (Waller, 2012).

The HEA relaunched *MSOR Connections* in 2013 as a peer-reviewed journal aiming to "promote, encourage, enhance and disseminate research, good practice and innovation in all aspects of the student learning experience within Mathematics, Statistics and Operational Research wherever these may be taught in Higher Education" (Kyle, 2013a). This iteration of *MSOR Connections* published just two issues in 2013.

In 2015, the journal was relaunched as a community initiative supported by the **sigma** Network and the University of Greenwich, which remains its current form. In a change to previous practice, a volume now covers an academic year. This iteration maintained *MSOR Connections* as a peer-reviewed, online-only, practitioner journal focused on "research articles, case studies and opinion pieces relating to innovative learning, teaching, assessment and support in Mathematics, Statistics and Operational Research from across HE" (Wilson, 2015). Volumes 14-18 contained three issues, with one issue of volume 19 published to date.

3. Method

3.1. Topic modelling

Topic modelling is explained in more detail elsewhere (e.g. Griffiths and Steyvers, 2004); here we give a flavour. Assume that a corpus of text documents are formed by selecting words from a number of topics, where each document has a set distribution of these words. So document 1 might select 50% of words from topic 1, 30% from topic 2 and 20% from topic 3, while document 2 might select 25% of words from each of topics 1 and 2 and 50% from topic 3, etc. Topic modelling takes an existing set of documents and attempts to generate the topics from which these might have been formed by assigning words from the articles into groupings. An advantage of this method is that there is no presumption about the topics that will emerge, so what results is theoretically an unbiased representation of the documents under study. As well as grouping words into topics, the method also assigns to each document the proportions of its text that are drawn from each topic, meaning the composition of each document can be studied. Subsequently, it is possible to review each topic and manually assign it a collective name, which aids interpretation.

An attraction of the approach is the efficiency of automation. A manual review of either metadata (titles and abstracts) or whole articles would yield richer data that could provide greater meaning in a qualitative analysis, but a review of nearly a thousand articles in this way would be onerous. Using this approach, we manually reviewed around 5-10 articles in each of our categories, with the rest left to automation.

One issue with topic modelling is that it requires the specification in advance of the number of topics to be generated, and methods for deciding how many topics to model are quite vague. One approach is to run the modelling with different numbers of topics and calculate the resultant *perplexity*. This measure "indicates the uncertainty in predicting a single word; lower values are better, and chance performance results in a perplexity equal to the size of the vocabulary" (Griffiths and Steyvers, 2004; p. 5230). Inglis and Foster explain "it is always possible to reduce the perplexity of a topic model by increasing the number of topics, but, at some point, the gain in fit will be offset by the increased difficulty of interpreting the larger number of topics", stressing that a major criterion for selecting the number is the interpretability of the resulting topics (p. 470).

We used MALLET 2.0.8 (McCallum, 2002), a toolkit for topic modelling, for this analysis.

3.2. *Locating and processing files*

The public location of articles of *MSOR Connections* is a complicated picture. During its history, it has been published by three bodies: volumes 1-12 by the University of Birmingham (holder of the MSOR Network contract); volume 13 by the Higher Education Academy; and, since volume 14, by the University of Greenwich on behalf of **sigma**.

When it was closed in 2012, the MSOR Network's website was archived by the Royal Statistical Society Centre for Statistical Education at the University of Plymouth, which later became the International Centre for Statistical Education and then itself closed in 2016 (International Centre for Statistical Education, 2016). Happily, the website archive is still active at http://icse.xyz/mathstore/ and contains an index of *MSOR Connections* articles.

Files downloaded from this archive were compared with a complete set of printed issues of *MSOR Connections* volumes 1-12. Where the number of PDFs differed from the number of articles in an issue, this was investigated. Often this happened because articles were combined in the same PDF file (perhaps because a short article shared a page with another), though there were a small number of cases where the article was simply missing from the MSOR Network website. Most of these missing articles were sourced instead from the Advance HE Knowledge Hub https://www.advance-he.ac.uk/knowledge-hub, an archive of HEA subject centre content (though note there are articles missing from the Knowledge Hub that do appear on the MSOR Network website, so neither offers a subset of the other). Five articles were not available in either location online, three of which have been obtained from personal contacts. This leaves two articles (Tyrrell, 2009; Hakim, 2010) that appear in the printed publications but are not available digitally, so were not included in the corpus analysed for this project.

When the Higher Education Academy relaunched *MSOR Connections* and other subject centre publications, it made a new website at http://journals.heacademy.ac.uk/ to host articles (Kyle, 2013b), assigning these articles DOI numbers (Kyle, 2013a). Unfortunately, this website was subsequently taken offline and the DOI references were not updated to new file locations, though all articles from a printed copy of volume 13 were found via searches on the Advance HE Knowledge Hub. Each article is in a separate PDF file.

All articles from 14(1) to 19(1) were sourced from the current journal website https://journals.gre.ac.uk/index.php/msor/. Each article is in a separate PDF file.

It is worth noting that the frequency of articles published has not remained constant over time, with more articles published in earlier volumes, but also that articles have tended to get longer on average over time, as shown in table 1. The fact that earlier volumes contained more, shorter articles than later ones might mean that they naturally exhibit greater diversity of topics.

From each article in volumes 1-12, the 'welcome' and 'diary' pages were removed and for volumes 13-19 the editorial and contents pages were removed. This is because these files contained only non-article content or content derivative of what is in the articles themselves (table of contents, editorial message and information about the MSOR Network). Advertisements for conferences, workshops and mathematical software were left in the corpus. These were much harder to identify, with small advertisements often included in article PDFs, and we feel are sufficiently relevant to the interests of the community at their time and small enough to not bias the findings here.

Table 1. Information on documents in the corpus from each volume.

Volume	Years published	Number of documents*	Total words** in documents	Average words** per document
1	2001	72	133592	1855
2	2002	77	137409	1785
3	2003	91	143950	1582
4	2004	83	123776	1491
5	2005	72	104273	1448
6	2006	70	112119	1602
7	2007	58	95717	1650
8	2008	55	100147	1821
9	2009	56	123559	2206
10	2010	50	94604	1892
11	2011	59	83964	1423
12	2012	33	63090	1912
13	2013	16	44370	2773
14	2015/16	22	59728	2715
15	2016/17	28	88186	3150
16	2017/18	22	79058	3594
17	2018/19	25	83171	3327
18	2019/20	21	80434	3830
19 (issue 1 only)	2020/21	8	26350	3294

* the number of documents does not precisely match the number of articles due to a small number of occasions where multiple articles are presented in the same PDF file in volumes 1-12.
** rough word count: this is the word count of all content in the PDF file after it was converted to plain text and should be considered approximate.

Over all issues, 918 PDFs were obtained. (Note that, for reasons discussed above, this does not map neatly onto the number of articles published, though it is close.) These include articles sharing practice and also conference and workshop reports, book and software reviews, and updates on activities of the MSOR Network and projects from members of the community. As such, the results of this study should be seen to reflect the interests of this community, not just the outputs of a research programme.

The PDF documents were converted to plain text using the Linux utility *pdftotext*.

We set MALLET to ignore words on its default English ‘stop list’, a list of 524 common words which are not likely to be topic-related (for an idea of these, a command to return three random words from this file returned “too”, “their” and “unlikely”). We also removed from the documents the following information:

- Information commonly found in footers of articles. These come in different formats during the run of *MSOR Connections*, for example “MSOR Connections Vol 2 No 2 May 2002”, “MSOR Connections Vol 11 No 1 Spring Term 2011”, “MSOR Connections, Vol 13, Issue 1 (April 2013)” and “MSOR Connections 16(3) – journals.gre.ac.uk”. These words were removed after initial tests found topic matches including words such as “msor”, “connections”, “vol” and the names of months.
- Author names. Some authors are prolific in the text, particularly MSOR Network staff in volumes 1-12. The index of articles from the MSOR Network website was processed, yielding 553 unique names. From these, surnames were removed from the corpus except where these were short (up to 3 characters) or common words (e.g. “Power”, “Ireland” or “Newton”). Again, some trial output had included author names and the aim here was to avoid the method producing a topic that is, for example, ‘articles by or citing Chris Sangwin’; we would rather focus the model on the article content.

Viewing the perplexity for up to 50 topics (see figure 1), we identified a drop around 30 topics and so one of us (PR) completed an initial assessment of the topic keywords for 30 topics, finding that there were some that appeared indistinct, for example there appeared to be two topics relating to workshops and conferences and three relating to running a maths support centre, as well as two or three topics that seemed a little generic. For this reason, 25 topics was felt to be adequate. The reduction in perplexity for adding many more topics is not large, and the 25 topics seemed sensible to interpret.

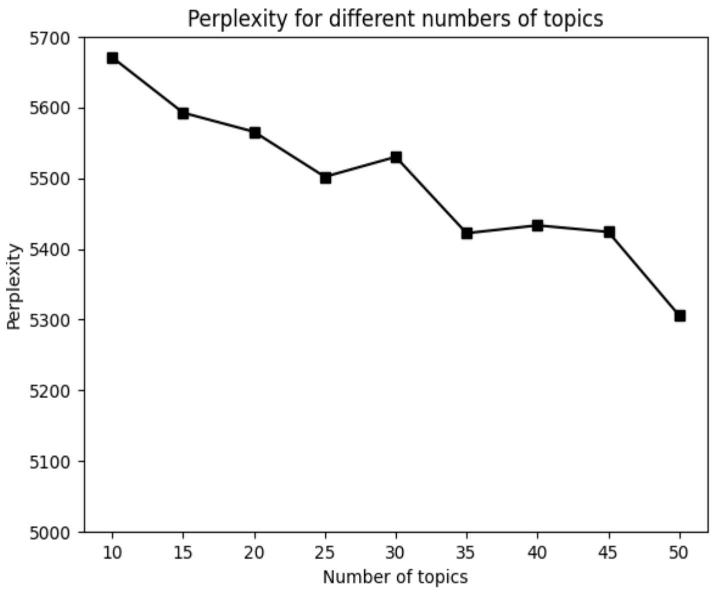


Figure 1. Perplexity of topic models for different numbers of topics.

The five articles with the highest proportion of words from each of the 25 topics were identified and stored along with the most common keywords associated with each topic. Both authors independently reviewed these and assigned names to each topic, then we discussed our lists. Nine topics were assigned with immediate agreement and a further fourteen with minor tweaks to phrasing; on two topics we differed meaningfully and these were resolved following brief discussion. This was informed by examining the documents with the highest proportion of words matched from this topic, though note that this is a simplistic process with issues. Some words have multiple meanings, some papers happen to contain words that appear relevant to a topic even though the paper overall might be an outlier. Also it may be that some papers have the highest proportion of relevant words, but are not necessarily indicative of the majority of papers matching that topic, which might have the topic as a minority element. For all topics we examined the five papers with the highest proportion of words from that topic; for those where further insight was needed, we looked at more papers as necessary.

4. Results

The list of topics with agreed labels is shown in table 2, along with the most common words associated with each topic. For each topic, we plotted the proportion of words in each volume of *MSOR Connections* that matched this topic and, as a simple indicator of trends, fitted each with a polynomial trend line. Figure 2 contains these plots using the same axis scales for ease of comparison. The period since the MSOR Network closed and *MSOR Connections* was relaunched as a fully peer-reviewed practitioner journal is shaded. This gives an indication of the popularity of each topic over time, though note that although volumes are a chronological progression, they are not quite linear; dates for each volume are given in table 1. Note that volume 19 has only published one issue of eight articles to date and the topics of these articles can cause sudden dramatic increases or decreases in the trend lines.

Table 2. Agreed list of named topics with the top characteristic words generated by the model.

Topic name	Top characteristic words
Assessment	assessment project learning students projects good year report work student writing criteria skills reports practice group final marking outcomes research
Book and software reviews	book material chapter matlab examples text exercises chapters student section page authors computing review introduction web teaching applets pages software
Computational software	maple version user software code file package mathematica users web features fig review files program tools java output windows tool
Conferences and workshops	conference mathematics university education research international group umtc mathematical computer issues teaching papers sessions delegates technology loughborough event dyscalculia workshop
Digital and remote learning	online video students audio digital university learning technology videos virtual accessed student screencasts screen time tablet media open technologies pdf
E-assessment question design	questions test question tests students quiz student diagnostic answer errors results correct answers exam feedback fig mark score set scores
E-assessment systems and technologies	assessment questions system mathematics question feedback computer mathematical caa learning input systems numbas e-assessment marking university answer answers stack implementation
Game play, outreach and the interaction of the two	maths school pupils mathematical university schools games mathematics activities game space science teachers activity arcade strategy outreach london project scheme
Graduate employability and skills development	skills mathematical curriculum development project graduate graduates work study sciences employers employability education degree careers business stem studies case developing

Table 2. Agreed list of named topics with the top characteristic words generated by the model.

Topic name	Top characteristic words
Interactive lecture technology, including classroom voting systems	students lecturer questions lectures class system lecture technology learning teaching response question classroom student feedback interactive answer answers systems evs
Mathematics on the web, including impact on accessibility	mathml latex text mathematics mathematical braille web content accessibility software xml notes access format word accessed visual equation read accessible
Maths support interventions to improve confidence and address anxiety	maths tutors support tutor students msc training sessions mathematics numeracy anxiety mls workshop workshops ireland postgraduate drop-in nursing university participants
Maths support provision	support mathematics students centre university engineering provision sigma institutions student mathematical learning staff centres resources maths statistics service universities provided
Modelling, simulation and industrial problems	engineering quality business engineers modelling design problems world control industry system project model projects company public team society management international
Online resources	project resources maths website university information web learning resource materials ltsn page site material stats online issue details contact email
Personal reflections of students and staff	good time teaching make maths work find problems experience years give things people interesting found university don’t notes problem learn
Problem-solving and mathematical approaches	students learning mathematics mathematical education problem research understanding teaching problems knowledge thinking study teacher concepts teachers develop solving approach examples
Proof, skills and understanding	mathematics mathematical proof theory examples students mathematicians proofs analysis theorem definitions numbers set language concept topic understanding history class physical
School-university transition	mathematics students level year mathematical schools courses universities curriculum subject subjects university school higher a-level education study engineering modules units
Staff development	teaching mathematics statistics education learning network university development staff research msor support higher practice community work programme centre activities training
Statistical data analysis	data statistics statistical analysis probability regression minitab distribution test methods fig sample results distributions model set introductory hypothesis teaching random
Student evaluation data	survey data table responses study results online questionnaire higher asked respondents questions response research education question performance reported analysis found
Student-centred approaches, including group work and peer support	students student year module group work staff time mathematics feedback groups engagement modules teaching learning week class study lectures sessions
Teaching specific curriculum items	students time number university case important general information provide form problems order part approach student present terms made common process
Teaching specific curriculum items using technology	geogebra function functions programming linear fig calculus solution equations algebra integration problem equation point numerical differential complex values points algebraic

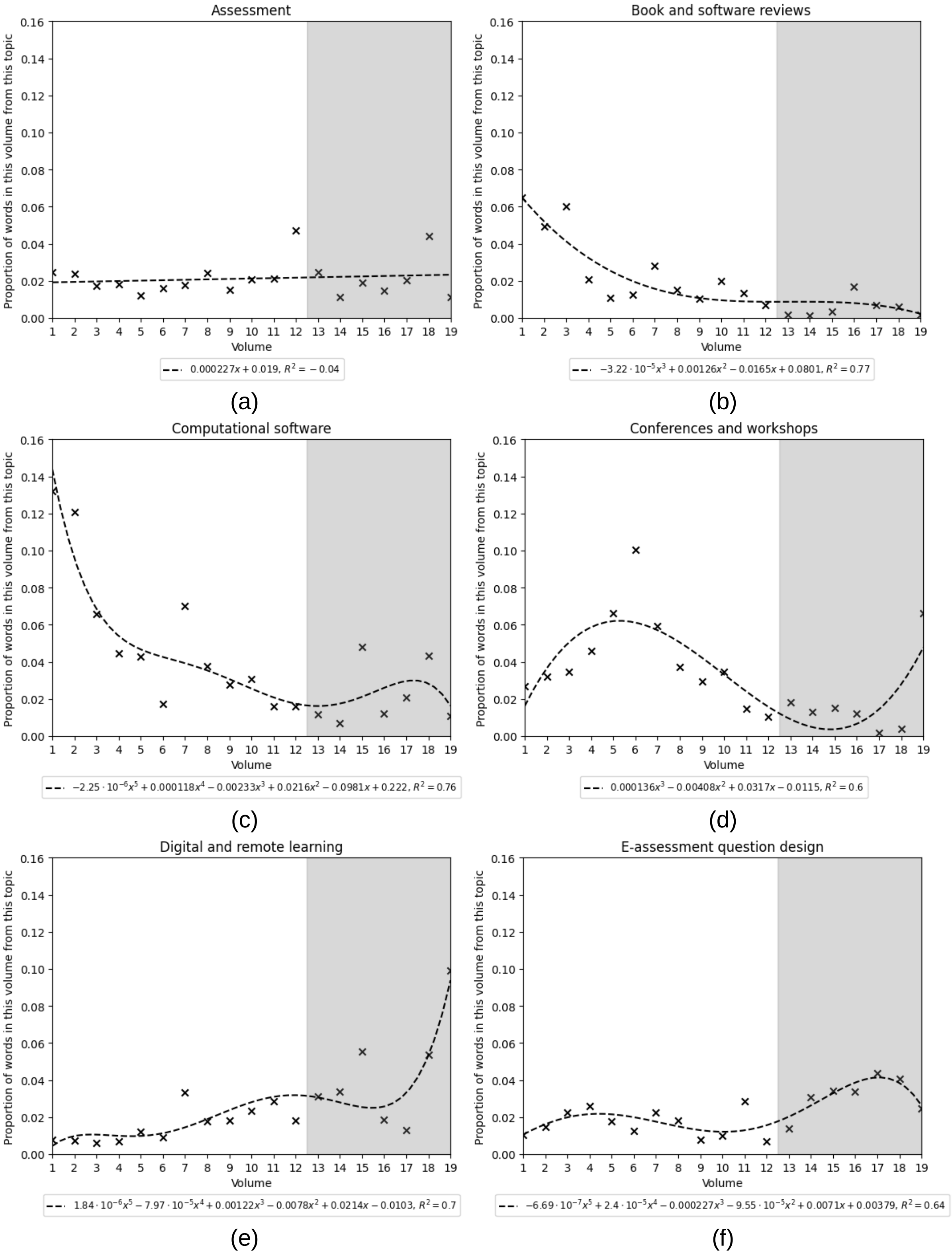
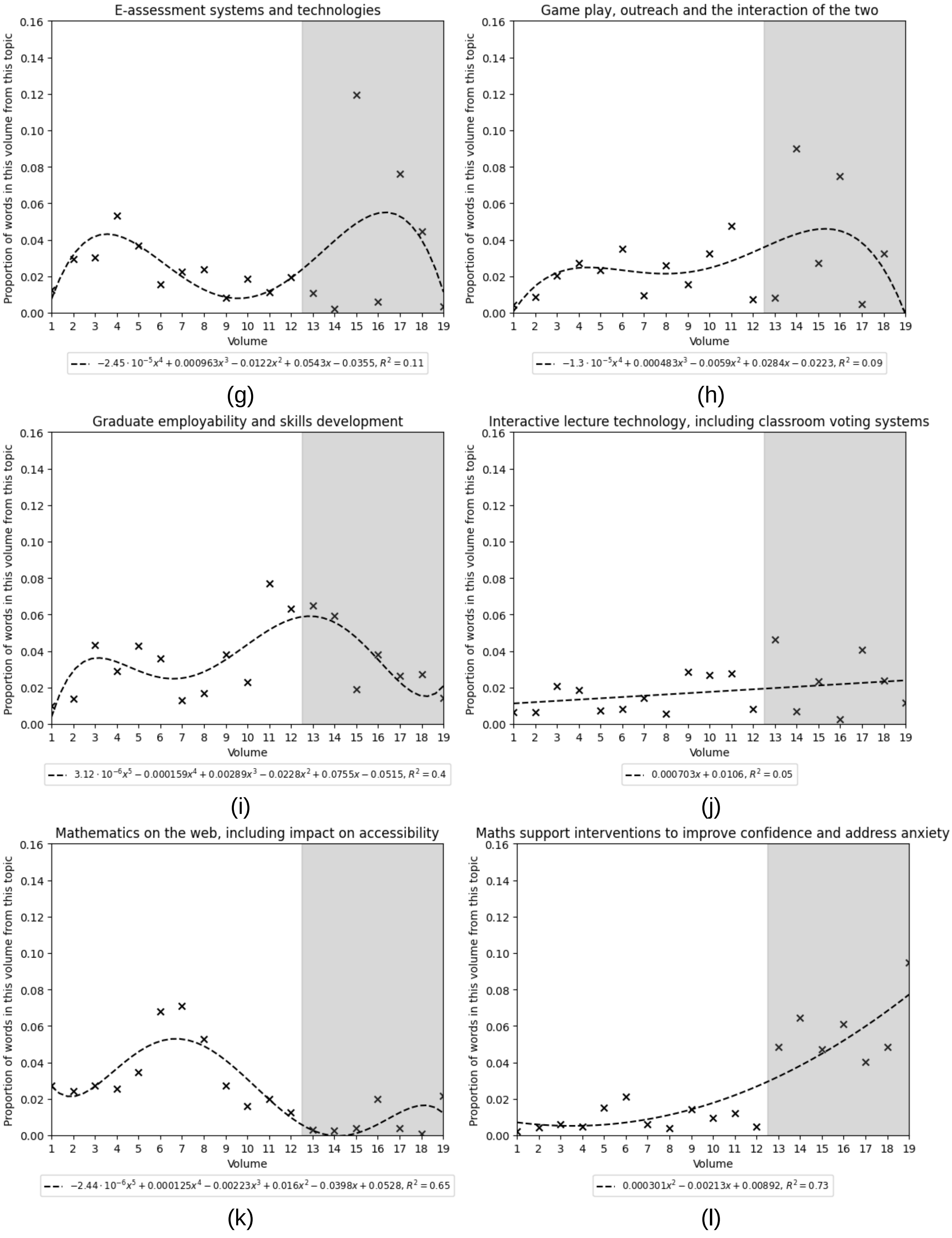


Figure 2. Proportion of words in each volume that relate to each topic. Trend lines are the polynomials with degree up to 5 that had the best fit (measured by R^2). Shaded region represents the period since the MSOR Network closed and *MSOR Connections* was relaunched as a fully peer-reviewed practitioner journal.



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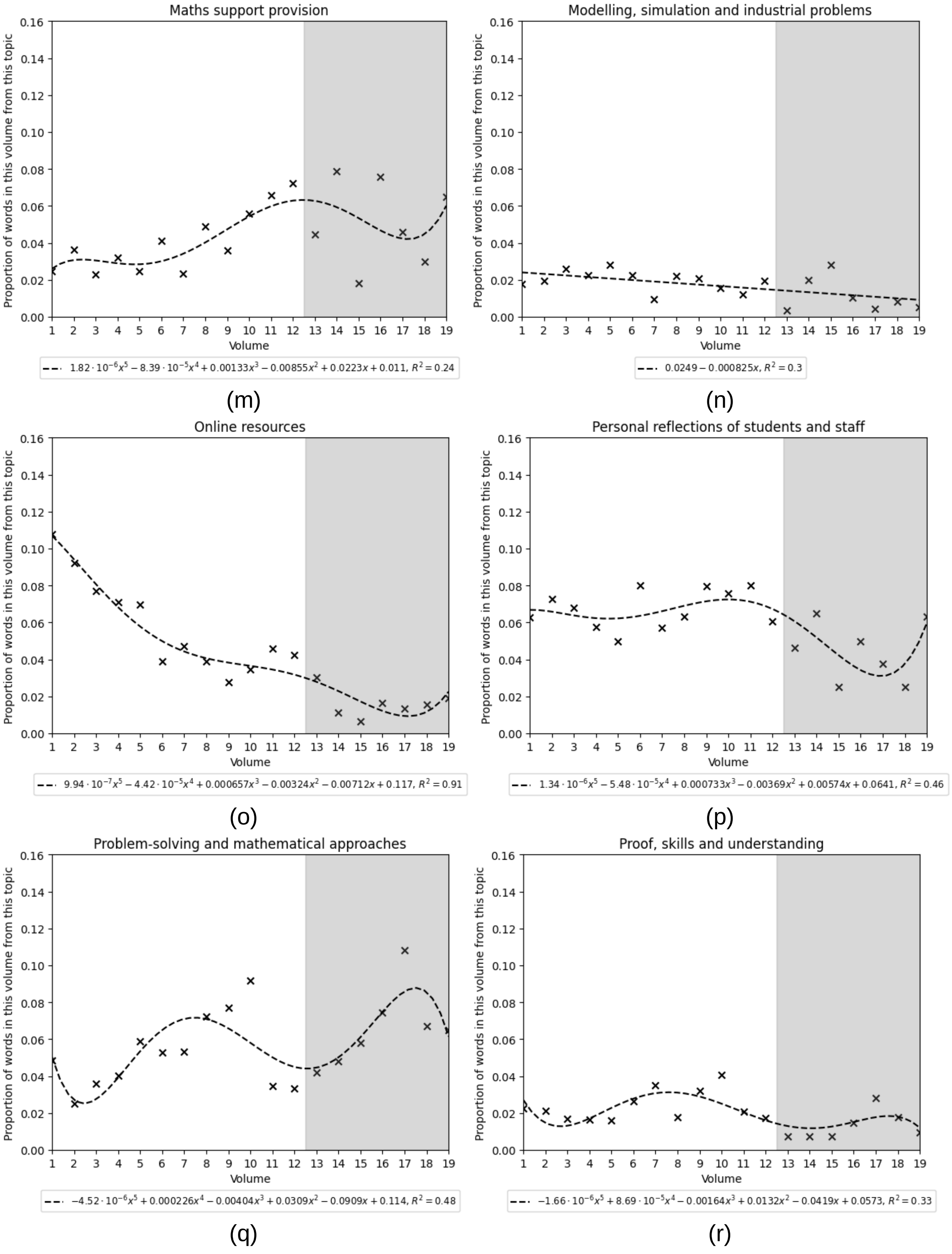

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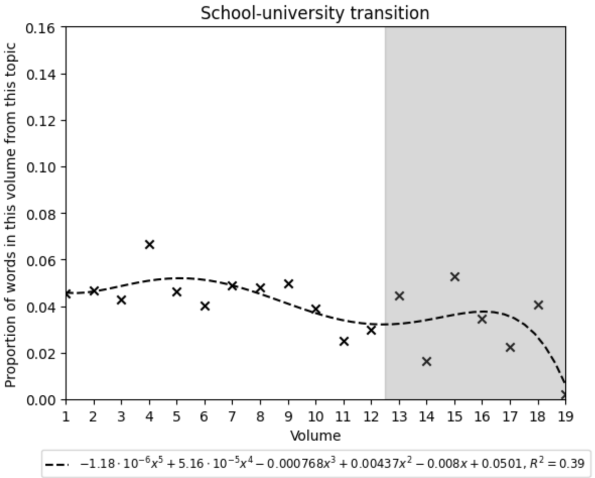

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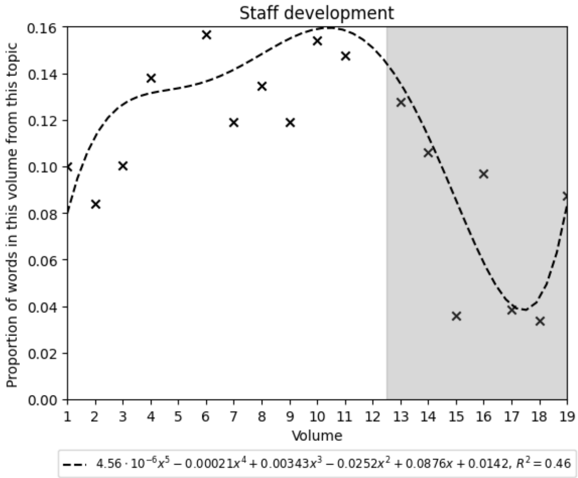

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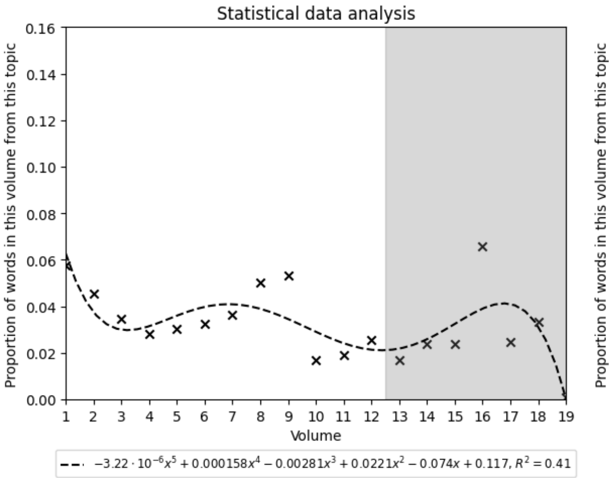

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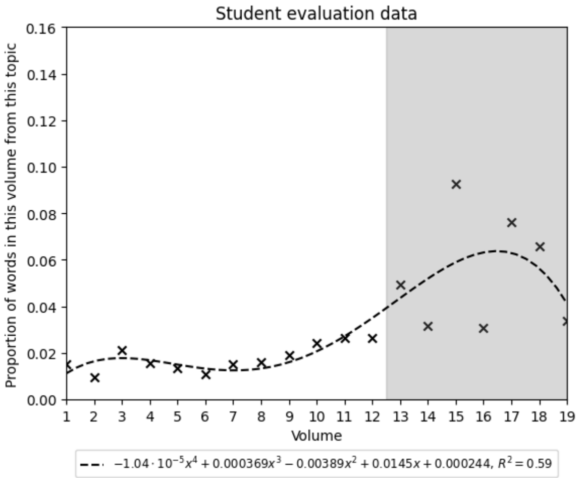

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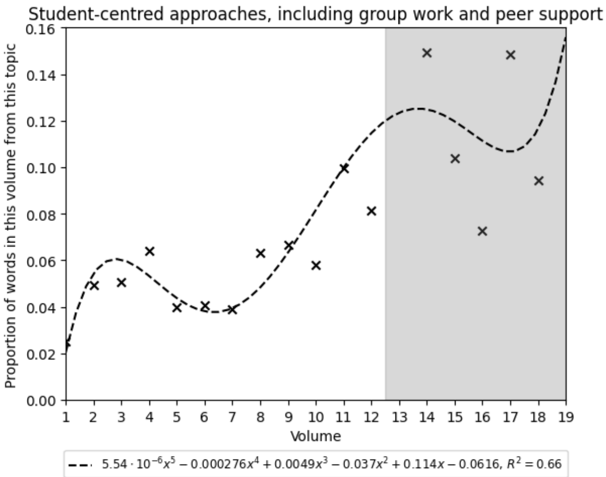

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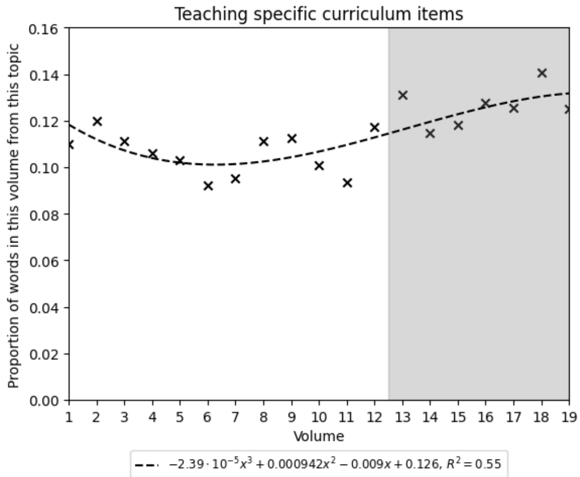
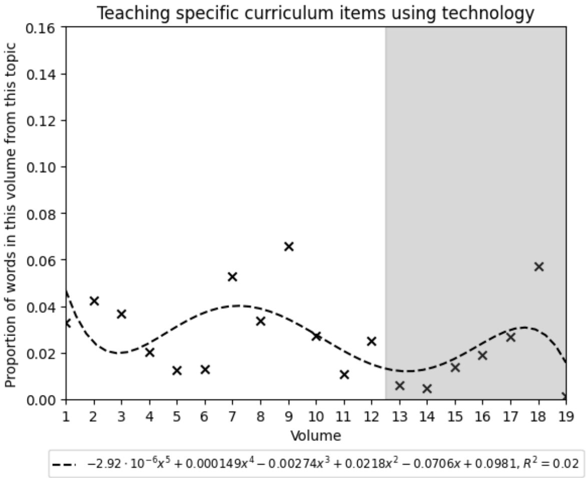


(x)

Figure 2. Proportion of words in each volume that relate to each topic. Trend lines are the polynomials with degree up to 5 that had the best fit (measured by R^2). Shaded region represents the period since the MSOR Network closed and *MSOR Connections* was relaunched as a fully peer-reviewed practitioner journal.



(y)

Figure 2. Proportion of words in each volume that relate to each topic. Trend lines are the polynomials with degree up to 5 that had the best fit (measured by R^2). Shaded region represents the period since the MSOR Network closed and *MSOR Connections* was relaunched as a fully peer-reviewed practitioner journal.

Next we briefly outline relevant context for each topic.

Assessment: Articles covering assessment as a general topic (e.g. Iannone and Simpson, 2012), as well as specific methods (e.g. peer assessment is discussed by Brignell et al., 2019).

Book and software reviews: Articles reviewing books or software, which used to be systematically organised by the MSOR Network. As a consequence of the Network's closure, this topic has declined in popularity (Figure 2(b)).

Computational software: Articles describing features of software and its use for teaching, including in software reviews.

Conferences and workshops: The key articles here are a mixture of adverts/announcements and reports from those attending or running such events.

Digital and remote learning: Includes articles concerned with online videos, screen annotations, and similar technologies. Note that the plot of popularity over time (Figure 2(e)) shows a sudden increase in volume 19, as articles related to the COVID-19 pandemic start to emerge (Heraty, 2021; Jones, Meyer and Huang, 2021).

E-assessment question design: Two topics emerged around e-assessment. We felt from examining the most relevant papers that this one related more to the design of questions for e-assessment systems for particular purposes, for example Martin and Greenhow (2004) discuss the design of questions to assess topics in linear algebra.

E-assessment systems and technologies: This second e-assessment topic seems to relate more to general features of systems and technologies. For example, Kawazoe and Yoshitomi (2017) discuss the design and development of an e-learning and e-assessment system.

Game play, outreach and the interaction of the two: This topic is a slight breakdown in the analysis, because it seems the relevant articles matched cover both outreach and widening participation (e.g. Easson, 2010) and use of games in higher education including for teaching game theory (Khan, 2017), which we would view as distinct topics. It's possible these have been grouped by the model due to some overlap around the use of games in mathematics communication (see, e.g., Steckles, Rowlett and Ugonna, 2020). We considered listing these as two categories, but ultimately decided this was not in the spirit of the project and anyway would severely complicate the analysis, for example the plot of occurrence of this topic over volume numbers in Figure 2(h) would no longer apply. Ultimately, it is a feature of the method that it uses no understanding of the topics involved and an analysis of topics in *MSOR Connections* using this method suggests that authors are writing articles about game play, outreach and their interaction which can be linked together, so that is what we report.

Graduate employability and skills development: This covers articles about the concept of employability and general initiatives (e.g. Hibberd and Grove, 2006) as well as specific teaching initiatives targeting skills development (e.g. Chadwick, Sandiford and Percey, 2011).

Interactive lecture technology, including classroom voting systems: Methods for increasing interactivity and engagement in lectures, particularly using voting technologies (e.g. Retkute, 2009).

Mathematics on the web, including impact on accessibility: These articles either relate to accessibility specifically (e.g. Maddox, 2007), or discuss the presentation of mathematics on the web, where increased accessibility is usually lauded as an advantage (e.g. Kaye, 2006).

Maths support interventions to improve confidence and address anxiety: Two topics appeared to relate to maths support. We felt this one related more to interventions, often delivered by maths support staff, that were designed to improve students' confidence and address maths anxiety (e.g. Ahmed, Joy and Moriarty, 2013), research informing such approaches (e.g. Sheffield and Hunt, 2007), and training designed to prepare tutors to deliver such interventions (e.g. Fitzmaurice et al., 2016).

Maths support provision: This second maths support topic appears to relate more to the organisation of a maths support centre or other provision (e.g. Croft and Robinson, 2003), and surveys of such provision (e.g. Ahmed, Davidson, et al., 2018).

Modelling, simulation and industrial problems: Articles relating to modelling and simulation topics, including those relating to simulated industrial problems (e.g. Chi, Pepper and Spedding, 2004).

Online resources: Articles here relate to online resources, particularly projects that generate and share such resources (e.g. Matthews and Croft, 2011).

Personal reflections of students and staff: The main articles in this topic cover a range of areas, but we feel the aspect that they have in common is that they were reflective and written from either the student (e.g. Harris, 2011) or staff (e.g. Baxter, 2005) perspective, or presented qualitative data from students (e.g. Thomlinson, Challis and Robinson, 2009).

Problem-solving and mathematical approaches: This includes articles about teaching problem-solving skills (e.g. Jones and Megeney, 2019) as well as articles about encouraging mathematical approaches to topics and problems, particularly in pre-service mathematics teachers (e.g. Bu and Haciomeroglu, 2010).

Proof, skills and understanding: This includes articles about topics such as proof (e.g. Alcock, 2009), modelling and estimation (Maasz, 2007) and applications of geometry (Arranz et al., 2009), which all seem to be written from the point of view of developing understanding. This topic also includes articles about the nature of mathematics and mathematical identity (e.g. Bangert, 2005), and the skill of mathematical writing (Hodges, 2004).

School-university transition: Mostly the top relevant articles discuss changes to the A-level curriculum in England from the point of view of informing university practice at the transition (e.g. Porkess, 2003), but this topic is also concerned with teaching practice at the higher education side of the transition (e.g. Leppinen, 2008).

Staff development: Articles specifically about initiatives around staff development. This topic has declined somewhat since *MSOR Connections* is no longer the newsletter of the MSOR Network (see Figure 2(t)).

Statistical data analysis: The main papers matching this topic relate to teaching the interpretation of statistical results, often from specific software packages (e.g. Ramesh, 2009).

Student evaluation data: The main papers matching this topic were a mixture of studies using survey data as their methodology (e.g. Cronin et al., 2017) and papers discussing the use of surveys (e.g. Farmer, Oakman and Rice, 2016).

Student-centred approaches, including group work and peer support: The top articles here cover a number of different areas, but we feel what they have in common is that they develop student-centred approaches, which includes working in groups (e.g. Rowlett, 2013) and peer support arrangements (e.g. Cox, Cook and Nield, 2016).

Teaching specific curriculum items: This topic contains what appears to be a mixture of articles, but on looking through we feel the common thread is that they all cover a particular topic in mathematics or statistics and discuss the teaching of this (e.g. Steele, 2007), as well as some particular discussions around developing thinking skills (e.g. Mason and Watson, 2001). Note that all papers here are relatively low relevance compared to other topics, meaning that this topic is likely to be a secondary focus for even the most relevant articles.

Teaching specific curriculum items using technology: Similarly to the topic above, these articles discuss the delivery of specific parts of the curriculum, but especially using technology to do so (e.g. Hood, 2009).

5. Discussion

This paper has used an approach called topic modelling to generate a list of topics covered by articles in *MSOR Connections* during its first 20 years of publication. Articles are not linked to one topic, but are a combination of several. There are many standard topics that will not come as a surprise to readers and have remained of consistent popularity over the years. These include general teaching and learning topics: ‘Assessment’, ‘Graduate employability and skills development’ and ‘School-university transition’. These also include mathematics-specific topics: ‘Maths support provision’, ‘Modelling, simulation and industrial problems’, ‘Problem-solving and mathematical approaches’, ‘Proof, skills and understanding’, ‘Statistical data analysis’ and ‘Teaching specific curriculum items’.

MSOR Connections publishing comes in two phases: 2001-12, when it served as both the newsletter of the MSOR Network in the UK and a practitioner journal; and, 2013-present, when it was relaunched in its current form as a fully peer-reviewed practitioner journal with a more international focus. In the first phase, the publication included news from and content developed by the MSOR Network. Consequently, it is not surprising to see a reduction over time in the topics ‘Book and software reviews’, ‘Conferences and workshops’ and ‘Staff development’.

In the 2013-present iteration, *MSOR Connections* included fewer, longer articles and was peer-reviewed. Some changes in topic seem to align to this shift, including the rise in popularity of articles featuring ‘Student evaluation data’ and the slight reduction in focus on ‘Personal reflections of students and staff’, which together might indicate a greater focus on evidence-based practice in the current journal.

It is not surprising to see that a journal with a focus on innovative practice has a high degree of content about digital technology, with nine of the topics relating to this. As technology has developed, though, it seems natural that there may be a shift in focus away from novelties and features of software, as well as the reduction in coordinated activity with the removal of the MSOR Network. The reductions in popularity of the topics ‘Computational software’ and ‘Online resources’ seem to fit this progression. The reduction in the topic ‘Mathematics on the web, including impact on accessibility’ seems to fit this pattern also, with methods for displaying mathematics more mainstream and embedded in standard software. However, we would note that accessibility remains a challenge for mathematics and statistics, and hope that this focus will continue to be considered by authors.

Some other topics appear to have developed a subtlety as they mature, or possibly are more relevant to a peer-reviewed journal than previously. ‘Maths support provision’ remains popular, but the specific topic ‘Maths support interventions to improve confidence and address anxiety’ has risen in recent years. Similarly, while ‘E-assessment systems and technologies’ remains consistently popular (though with peaks in 2015 and 2017 when *MSOR Connections* collected articles from the E-Assessment in Mathematical Sciences conferences), the specific interest of ‘E-assessment question design’ seems to have risen in popularity recently.

There has been a general rise in the topic ‘Student-centred approaches, including group work and peer support’, which may indicate a trend in undergraduate mathematics education practice towards a broader range of delivery and assessment approaches.

Finally, we reserve special comment for the topic ‘Digital and remote learning’, which has maintained a fairly consistent popularity over the years, but with an uptick in the first issue of volume 19. We expect this topic, in itself and manifested in ‘blended’ approaches, to make a step-change in popularity over the coming issues as the short- and long-term consequences of increased remote working due to the COVID-19 pandemic make themselves known in the journal.

We are cautious about recommending implications following this research. First, it was our intention to hold a mirror up to the community and so to encourage self-evaluation by its members. Second, we are wary of an article co-authored by editor of the publication offering advice for those who might write content for it, as *MSOR Connections* looks to serve its community rather than direct its interests.

That said, we encourage readers to view the results here and consider the areas in which others are developing their practice. Potential authors might note that some topics have declined in popularity and consider whether this is because the field has matured and there is now less to say, or whether a topic is overdue a revival. It may be worth reflecting on the rise in interest in student-centred approaches, and the development of specific foci within student support and e-assessment, that may indicate developing interests of the community. Again, we leave it to the individual reader to judge whether this indicates a direction for their own practice or research, or whether they wish to develop alternative, understudied areas.

We might speculate about missing topics. One topic that does not occur in our analysis but which has a lot of current interest is equity, equality, diversity and inclusion. For example, in our country there have been recent mathematics-specific initiatives such as the Black Heroes of Mathematics Conference (Tabiri, 2021) and the LGBTQ+ STEMinar Conference series (https://lgbtstem.wordpress.com/lgbtsteminar-conference/) joining well-established work on women in mathematics (e.g. https://www.lms.ac.uk/womeninmaths), as well as broader higher education conversations e.g. around decolonisation of the curriculum (Stone and Ashton, 2021). Such topics are also being discussed internationally. We might expect this general interest to develop into specific discussion by authors in this journal in the coming years.

The topic modelling method is somewhat context-independent, in that the allocation of words from articles into topics is done without knowledge of underlying context. This is a strength for unbiased analysis, meaning the groupings of key words and relevant articles is done without prejudice. This can, though, lead to the generation of topics we might not see as wholly linked, as is the case here where articles about game play and outreach are put together because of some overlap despite being quite disparate. And the method is not without potential bias: a different analysis could have been performed by choosing a different number of topics to analyse, and there is some interpretation by the authors in assigning names to the topics. It is also worth noting that our assessment of the different topics is based largely on the key words generated and the top articles matching that topic, which may mean that subtleties in the topics are lost, especially where these are common in articles that only moderately relate to a topic.

Overall, we hope this analysis has shone some light on the sorts of topics and trends in topics that the journal is experiencing, and that it will provide a call to action for authors wishing to either contribute their work on an existing topic or, perhaps more excitingly, write articles developing a new topic that has not surfaced in this research.

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OPINION

Welcoming students to the mathematics community: obstacles to "belonging"

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Abstract

This paper reflects on some of the obstacles which lead some students, particularly those from non-traditional academic backgrounds, to question whether they "belong" to the mathematics community.

Keywords: Retention, transition, student success, belonging, community, barriers, attainment gap.

1. Introduction

"I loved mathematics and I was good at mathematics; I was also certain I did not have what it took to be a mathematician." Hottinger (2016) recalls her feelings as a woman studying mathematics who chose not to apply for graduate studies in the discipline. Many mathematics students experience similar doubts as to whether they really belong in the mathematical word.

Undergraduates studying mathematics degrees are joining the mathematical community. Like all communities, ours has its own language and conventions, and for some undergraduates, unfamiliarity with these may lead them to feel that they do not belong in the community. Some aspects of the history of the subject, if not addressed by their teachers, may also lead some potential mathematicians to feel unwelcome. This is particularly so for students from non-traditional academic backgrounds.

We discuss some of these potential barriers and how higher education mathematics teachers can help students come to feel that they belong.

This paper has been heavily influenced by two valuable short articles on "mathematical microaggressions" by Francis Su, who at the time was President of the Mathematical Association of America (Su, 2015 and Su, 2016).

2. Potential barriers

One barrier to a feeling of belonging to a community is the feeling that "people like me" do not belong to the community. The two authors of this paper had different feelings when they enrolled on their mathematics degrees.

When Tony arrived at university to study mathematics, he did not doubt his right to be there. The following factors helped.

- He was white, male, middle class and was joining straight from school
- Both his parents had been to university (and all his siblings would do so too)
- He had been to a school from which over 95% of the students went to university

- Two schoolfriends were starting on the same course at the same university
- A very famous mathematician of the time had been a former pupil of his school
- There was a history of students from his school studying mathematics at this university
- Tony's school maths teacher had recently studied at that university and had introduced the relevant culture (in contrast, many school students today are taught mathematics by teachers who have studied other subjects at university)
- He had read traditional mathematics books and was familiar with traditional mathematical writing styles

But for many new mathematics students today, few of these factors may apply.

In contrast, Noel-Ann started her undergraduate degree as a mature student in her late 30's.

- Despite having attended a 'good' school she had not done well at A-level and was convinced she would be the worst student on the degree.
- She was worried that all the students would be school leavers and so she would not fit in.
- She had not done any formal mathematics for about 20 years.

Recalling his own feelings as a new student, Tony was taken aback by a recent conversation with some students. As a measure to help new students settle at university in the first few weeks of their first year, selected current students were assigned to mentor groups of new students. At a training session for these mentors, they were asked to describe how they had felt on arrival at university. These were successful students who were confident enough to volunteer to be mentors, and Tony expected that they would recall feelings of excitement, tinged with anxiety. However one word dominated: that word was "terrified". The strength of this feeling, and that it was shared by all the students in the group, shocked and dismayed Tony. Tutors need to be aware just how uncertain many – perhaps most – new students feel about their arrival at university, and work to foster the sense that students belong in their new environment. Initiatives such as the Maths Arcade and mentoring schemes for new students are relevant here (Bradshaw 2011, Bradshaw 2017, Rowlett et al 2019, Grove et al 2015).

This paper focuses particularly on the subject-specific feeling of belonging and will discuss some barriers which may cause students to feel that they are not members of the mathematical community. For a very recent discussion of the challenges facing some mathematicians see Crowell (2021).

2.1. (Lack of) role models

"I get a lot of letters from young queer scientists. They get hope for their professional futures just knowing I exist. Imagine that. Imagine not knowing anyone like you in your field. Imagine not even hearing of anyone like you" (Kent, 2019).

As mentioned above, Tony was aware of many examples of "people like him" studying mathematics at his university and had no reason to doubt his right to be there. On the other hand, Noel-Ann has no recollection of any role models for mature women students. The visibility of diverse role models can reassure students that "people like them" belong to the mathematics community. Examples of initiatives to provide such role models and other resources include:

- The book *Living Proof: Stories of Resilience Along the Mathematical Journey*, published by the American Mathematical Society and the Mathematical Association of America and available as a free ebook (Henrich et al, 2019)

- Irina Linke and Eugenie Hunsicker's video "Faces of Women in Mathematics" (Linke and Hunsicker, 2018)

- The "Mathematicians of the African Diaspora of the Twentieth Century" website (Williams, 2021)

- The website "Mathematically Gifted & Black", "Featuring the Accomplishments of Black Scholars in the Mathematical Sciences" (The Network of Minorities in Mathematical Sciences, 2021)

- Nira Chamberlain's presentations on "The Black heroes of mathematics" (eg Chamberlain, 2020)

- The website of Lathisms, which presents "Latinxs and Hispanics in the Mathematical Sciences" (Lathisms, 2021)

- Profiles on the Institute of Mathematics and its Applications (IMA) "Maths Careers" website (IMA, 2021a)

- The IMA's "Diversity and Inclusivity" web page, which at the time of writing links to pages on BAME (Black, Asian and Minority Ethnic), Disability and Neurodiversity, Gender Diversity, LGBTQ+, and Women in Mathematics. (IMA, 2021b).

- The London Mathematical Society (LMS) "Success Stories" website (LMS, 2021)

- Chalkdust magazine's Black History Month (Chalkdust, 2019)

Such resources are potentially valuable in helping undergraduates from different backgrounds feel the community of mathematicians does contain people like themselves.

2.2. (Lack of) inclusivity in examples

It is not only the absence of role models that can lead some to feel that the mathematics community does not include people like them. Students learning mathematics will come across many examples illustrating applications of the material they are learning. These examples may refer to imaginary people. Intuitively, it might seem that vivid examples help in learning mathematics, and concrete examples are often more helpful than abstract ones, so it is natural to give names to the people who feature in examples or exam questions. (However the value of concrete rather than abstract examples in learning mathematics has been challenged, for example by De Bock et al (2011).)

If your name is Mary or Ahmed, for example, and if the problems you meet in your mathematics exercises always refer to people called Michael, Peter, and William, then you may infer a message that people like you are not expected to study mathematics. So, to make our students feel welcome, we should strive to make sure that the names we use in our examples reflect diversity in gender and cultural background. However, the question of names is complicated, not least because of the sensitivity we as human beings have about our names and our cultures, and because we are not confident about using names from other cultures. Possible approaches include

- Avoiding using names completely (which means abandoning a tool which helps students engage)
- Using names which might come from different genders and cultures, like “Ali” and “Lee”
- Using names drawn from previous students from different cultures
- Use random name generators which draw names from a representative database

Each of these approaches has its limitations!

It is not only names which can exclude students. If you identify as LGBTQ+ and a mathematics class presents a “marriage theorem” in which men are paired with women, or if you are non-binary, and a logic class presents “gender” as a binary property, then you may feel excluded. (It is not surprising, perhaps, that there are different views on these issues. An Australian lecturer’s attempt to discourage the use of the word “marriage” in discussing matching theorems led to press reports of a hostile reaction from at least one student (SBS News, 2017).)

In creating examples to illustrate mathematical ideas, we tend to choose settings with which we are familiar. But our background is often different from that of our students, and these settings may not help their sense of belonging. People do not all have exactly one job, children may not have piano lessons or study ballet, and summer holidays and going to the theatre may be unfamiliar concepts for some of our students. Examples about football or television programmes may engage some students but alienate others. References to music or films may not be understood by young people from different backgrounds, and, more importantly than not understanding, they may feel that they are in some way at fault because they don’t meet tutors’ expectations. Humour can be particularly problematic for the student who does not “get” the joke, but humour is also a valuable tool in engaging students and building a relationship with them.

An example discussed by Su (2015) is the well-known Fermi problem of estimating how many piano-tuners there are in the UK. Tony has used this with students, aiming to boost their confidence by showing that they can come up with a good estimate for a problem they haven’t previously considered. But students may not know what a piano-tuner does, or may assume that, like a guitarist, a serious pianist tunes their own piano. Since the value of the exercise is to show students that they can solve unfamiliar problems, is that a problem? Well, it is a problem if the students think that they are expected to know all about piano-tuners in advance. So it is important to be clear to students about the purpose of the exercise and that there is no expectation that the problem will be familiar to them.

There are examples of mathematical results (such as the marriage theorem mentioned earlier) which are traditionally presented in contexts which, today, would be considered inappropriate by some. Another example is the “Battle of the Sexes” in game theory (Wikipedia, 2021). In the original formulation, this posts that a man and a woman hope to meet at either a prize fight (preferred by the man) or a ballet (preferred by the woman). They cannot communicate: which should each go to if they want to be at the same event as the other? (Apparently, some recast the problem as “Bach or Stravinsky” rather than “fight or ballet”. It seems unlikely that that would make the example more relevant to most of today’s students.) Of course, quite apart from the gendered assumptions about preferences, in the days of mobile phones it might be hard to persuade students that this is a real-life problem!

This raises a question. These problems, and their traditional formulations, are part of the culture of mathematics. They can be found in standard textbooks, some of which might be recommended reading for students. When they were created, there was an element of humour: these were not proposed uncritically as realistic real-life problems. To what extent should we, in aiming to be inclusive, avoid referencing past examples which are now problematic? Are we helping students to belong, or in fact, by denying them access to traditional mathematical presentations, even perhaps achieving the unwanted result of excluding them from mathematical culture?

While there is no simple solution, awareness of the potential issues, understanding that one's own cultural context may not match that of students, and an attempt to use diverse examples and references, may help reassure students that they are not being intentionally excluded.

2.3. Mathematical language and notation

The culture of mathematics includes use of language in ways which are sometimes subtly different from standard English usage. This may confuse students who are not familiar with the nuances of mathematical discourse, and lead them question their ability to study the subject.

For example, the words "infinite" and "unlimited", in everyday language, are often used just to mean "very large", while in mathematics they have more precise meanings. Similarly, to many laypeople, "theory" suggests an unproven hypothesis, whereas in mathematics terms like "group theory" refer to an established body of proven results. The term "proof" also has somewhat different meanings in mathematics and everyday life.

A few years ago Tony saw a mobile phone contract advertisement offering "unlimited data" which, in the terms and conditions, was very specifically limited to something like 5GB per month. He was sufficiently irritated by the use of "unlimited" to describe something with a very specific limit that he wrote to the Advertising Standards Authority, whose reply indicated that there was no problem because "unlimited" simply means "very large" and does not imply that there is no limit. Rightly or wrongly, that is the usage with which students are likely to be familiar.

Particularly sensitive is the mathematical use of words like "trivial" and "obvious". There is the old joke about the mathematician who says in a lecture "this result is obvious", then hesitates, spends several minutes considering, concludes "I am not sure this is obvious", and then after further thought comes back the next day and says "Yes, this is obvious". The point is that when mathematicians use the word "obvious" it does not imply that you should be able immediately to see why the result is true – it may take some thought. But for a student unfamiliar with this use, they may feel "I don't see why this is true therefore I am not good enough to be a mathematician". The word "trivial" has similar negative connotations in everyday language – Tony remembers an occasion when a leading mathematician was berated on an online history of mathematics forum when they used "trivial" to describe the proof of a mathematical result and some readers found the use of the word insulting. These examples show the sensitivities around the use of language, and indeed variations in different mathematical cultures.

Notation may also present challenges for students. For example, mathematicians make frequent use of Greek letters. Whereas Tony had studied ancient Greek at school and had no problem with this, students today are unlikely to have this advantage. Indeed, for many English will be a second or third language, and for some the Latin alphabet will not be used in their native language. (Tony recalls struggling with a textbook which used old German capital letters to denote algebraic structures: he could not tell them apart, and didn't have the sense to practice writing them himself until they became familiar.) While students may need to gain familiarity with Greek letters in order to follow mathematical expositions, teachers should appreciate that they may not arrive at university with this facility.

Students may not have a full understanding of mathematical terminology and may not appreciate the distinctive features of a “theorem”, a “lemma”, a “corollary” and other technical terms. While part of the process of becoming a mathematician is to come to understand these terms through experience - through seeing them in action - in addition to learning from definitions - once again tutors might think about how they can help students develop their understanding of mathematical language.

So these examples - using words in a mathematical sense, or using symbols that may be new to students - might lead students unfamiliar with the practices to feel that they don’t belong. But on the other hand belonging to the community requires understanding these usages and therefore it is important that students be exposed to mathematicians’ use of language.

There is tension here – we want to help students belong to the mathematical community, and to understand the nuances and conventions of mathematical language and notation, but these can be a barrier for those new to the community. So tutors need to be sensitive to the potential difficulties students might have, and offer students support in learning how mathematicians communicate. They should consider whether it is necessary to explain the mathematical use of terms like “unlimited” and “obvious” when they use these words in their classes, and should consider whether students will have met the notation and symbols they use. While study of traditional mathematical textbooks will help students appreciate the standard language of the discipline, students increasingly turn to online resources and videos to support their learning, and these may not present such clear models. Bradshaw and Richardson (2013) describe an initiative to encourage mathematics students to read books about the subject – many (though not all) popular mathematics books do show how “insiders” express mathematical ideas.

As with other issues discussed in this paper, there are not always easy solutions, but if tutors are aware of the potential for students to feel excluded, their sensitivity may mitigate the adverse effects.

2.4. The difficulty of mathematics

University mathematics can be difficult. Practising mathematicians do not find their work easy. New ideas take time to assimilate: as John von Neumann famously said to a friend, “Young man, in mathematics you don't understand things. You just get used to them.” (Wikiquote, 2021). Most of us are familiar with difficult mathematical ideas which took us days, weeks or even years to fully understand.

But this has not been the experience of some of our students. For those to whom school mathematics came easily, meeting mathematical ideas which they don’t immediately grasp is a new experience, and one that can cause them to wonder whether they are good enough to succeed in the subject.

So it is important to prepare students for the experience of coming across deep ideas that require time to appreciate. We need to be clear that University-level mathematics is challenging and that students will at times, and perhaps frequently, experience the frustration of being “stuck”, and that this does not in any way mean that they are inadequate, or not fit to be mathematicians. References to the struggles of famous mathematicians (like Andrew Wiles’s seven years of working on Fermat’s Last Theorem) or to published accounts of their work (Villani, 2015) may help. Suggestions of strategies for dealing with being stuck may not only be practically useful but will reassure students appreciate that this is a normal part of doing mathematics.

Of course, there is a balance between warning students of the demands of the subject, and putting them off by over-emphasising the difficulties! But it is important to be aware that the difficulty of the subject may cause some students to doubt whether they really belong.

3. “Decolonising the curriculum”

The topic of decolonising the curriculum is currently being debated in universities which are anxious to eliminate the attainment gap between students of colour and their white peers. This concept may be controversial, with some departments being unsure how it is relevant to the teaching of an abstract subject like mathematics. Rather than defining the term here, we intend, for the purpose of discussion in this section, to discuss more broadly how we might avoid our mathematics curricula and teaching creating an unwelcoming environment for some potential mathematicians – an objective which we believe all mathematics teachers would support.

This topic is important for many reasons, but this current paper will suggest only that teachers might consider whether the current curriculum, in this regard, might in some ways present obstacles to “belonging” for some students of colour, or other groups, making them feel uncomfortable or unwelcome. There are of course other reasons why this aspect of the curriculum is an important concern, but these are not the point of this article.

Do our mathematical curricula take the opportunities available to present mathematical ideas from different cultures? For example, pure mathematicians see the concept of proof as central to mathematics. The traditional view that proof originated in ancient Greece has been challenged, for example in the essays by many authors collected by Chemla (2012), which show that Mesopotamian, Chinese and Indian knew how to demonstrate the correctness of their methods. How far might we broaden our curriculum to inspire students by celebrating the diverse origins of our subject and the mathematics of different cultures.

Sometimes there might be easy “wins”. For example, Tony has been teaching a module on codes and cryptography. This began by presenting historical examples of codes, such as semaphore and Morse code (which Tony remembered from Boy Scout books, but which are probably less familiar to today’s students). But examples from other cultures – African drum communications, native American smoke signals – are not only equally relevant, but positively enrich the module and demonstrate the universality of the concepts being introduced. So a minor tweak to the module content, in a situation like this, can have immediate benefit.

There are other issues arising from the history of mathematics. Recently the statistical community and the Royal Statistical Society (RSS) have confronted the fact that several of the pioneers of mathematical statistics in the last century were involved in the eugenics movement and expressed racist or anti-Semitic views (Langkjær-Bain, 2019; RSS, 2019). Buildings, lecture theatres and prizes previously named after Karl Pearson (1857-1936), Francis Galton (1822-1911) and Ronald Fisher (1890-1962) have been denamed. (UCL, 2020; Rothamsted Research, 2020; Committee of Presidents of Statistical Societies, 2020; Gonville and Caius, 2020).

The UCL statement about its denaming of the former Pearson Building and Pearson and Galton Lecture Theatres quotes its then Provost, Professor Michael Arthur, who said “Although UCL is a very different place than it was in the 19th century, any suggestion that we celebrate these ideas or the figures behind them creates an unwelcoming environment for many in our community.” This captures the threat posed to the sense of belonging by the apparent celebration of people who, although they may have contributed significantly to the advancement of science, expressed abhorrent views.

In this paper we use Karl Pearson as an example, since he has been in the news regarding this issue: we are not suggesting that his actions are necessarily more reprehensible than those of many other mathematicians of the past. Several other examples of mathematicians whose words and actions are unacceptable today are discussed by Bingham (2020), while Fara (2021) shows that the science of Isaac Newton and the early scientific community of the Royal Society have uncomfortable connections with the slave trade. In light of current interest in these topics, it is likely that such cases will continue to feature in news stories.

How would you feel about learning about the mathematics of someone who described people like you as “inferior physically and mentally to the native population”, as Pearson and Margaret Moul wrote about Jewish immigrants (Pearson and Moul, 1925)? (Of course, many readers may have personally experienced such situations.) There are anecdotal reports of students at a UK university objecting to a module taught using the Moore Method, the enquiry-based learning method associated with R.L. Moore (1882-1973), because of Moore’s racism – he refused to teach Black students and walked out of a seminar when he realised the speaker was Black (Wikipedia 2021b). If your tutors are presenting, without any apparent uncomfortableness, the mathematics of those who considered people like you as inferior, do you feel that you are really welcome in the class? Where we are aware of racist or sexist context relating to the mathematics we are teaching, perhaps we owe it to our students to acknowledge this explicitly in our teaching.

How might students feel about using results named after mathematicians who behaved offensively? For example how does a student who is aware of Pearson’s racism feel about using “Pearson’s correlation coefficient”? How would any of us feel about using “X’s Theorem” if X were, say, a mass murderer or child abuser? (Of course, this problem is not new. Mathematicians refer, for example, to the Bieberbach Conjecture, named after Ludwig Bieberbach (1886-1982), who was an active Nazi, and to the Bloch Space and Bloch Constant, named after André Bloch (1893-1948), who murdered three members of his family (Wikipedia 2021c, 2021d). And it arises in other areas of life – how should we regard books, films or music written or performed by people responsible for reprehensible actions or writings?)

It can be argued that naming a mathematical result after a mathematician associated with it is simply an attribution and does not imply any celebration of any other aspect of that mathematician’s life. As historians are aware, people are complex, change their views, say and write things they later regret, and are very much influenced by the culture of their time. Very few of us will avoid expressing opinions or carrying out actions which will seem reprehensible to posterity.

Bingham (2020) argues that we should stop using names of mathematicians and refer to results descriptively rather than using the creator’s name. There have already been moves to rename some mathematical results. For example, “Travelling Salesperson Problem” is used instead of “Travelling Salesman Problem”, and “Route Inspection Problem” instead of “Chinese Postman Problem” (Wikipedia 2021e, 2021f). So although renaming mathematical results might cause some confusion to students consulting older books, there are already precedents.

A workshop exploring this issue at the University of Greenwich, led by the second author and a mathematics graduate who had been President of the University’s BAME (Black, Asian and Minority Ethnic) Society, found that students were divided about measures such as denaming mathematical results, with most feeling that there are complicated and potentially divisive issues with no simple solution. However they did feel that lecturers should provide context for the mathematics they are presenting. We could present Pearson’s work, and credit him for his mathematics, while acknowledging the offensive aspects of his life. We could indicate the racist and sexist nature of the societies which produced the mathematics our students are learning.

So one strategy for avoiding creating an “unwelcoming environment” for students would be, rather than hiding or ignoring the racist nature of important mathematicians and the cultures in which they lived and worked, openly to discuss the issues. We might explicitly acknowledge the flawed nature of the human beings who contributed to our subject and the regrettable aspects of their times, celebrating the mathematics while deprecating the unpleasant aspects of the cultures in which it was developed and the failings of its creators.

4. Assessment

Students may doubt their place in the mathematics community if they are assessed by methods which don’t allow them to demonstrate their individual abilities. The question of assessment in mathematics is a topical one (MEI 2021), and many UK universities explicitly encourage the use of a range of assessment types in all disciplines. Although many academic disciplines at UK universities have moved away from traditional timed examinations, these still comprise a large part of assessment in mathematics at most universities in the UK, and this (regrettably, in the view of the authors of this paper) has, in many cases, not changed significantly over the last ten years (Iannone and Simpson, 2021).

Students who have been well prepared for examinations at school and have achieved good results in previous exams may enjoy this form of assessment, and may dislike and distrust alternatives. Some international students trained under different educational systems may have no experience of other assessments and will not expect to be assessed in any other way (and may not appreciate UK conventions around plagiarism in coursework).

But on the other hand formal examinations can be intimidating. Many students are very apprehensive about taking exams and prefer being assessed in other ways. This may particularly apply to those who have been educated at less academic schools or who have studied school qualifications which are not primarily assessed by examination. Anecdotal evidence from applicants to university in 2021 suggests that the disrupted A-level experience for those taking the qualification in 2020 and 2021 has left many students very nervous about the prospect of university examinations.

Both authors of this paper have seen many examples of mathematically able students who, under the stress of formal examinations, were unable to perform to their potential in assessments which contributed significantly to their degree outcome. The authors have doubts as to whether examinations are a reliable form of assessment and whether they benefit students’ and teachers’ physical and mental health, and would argue for variety of assessment methods in mathematics degrees. (There is discussion of the merits of different forms of assessment for mathematics in MEI (2021).)

The question of assessment in mathematics is a large and important one, deserving fuller analysis and discussion than space permits here. In this context the authors simply wish to identify that the forms of assessment used in higher education may have a profound effect on students’ self-belief as aspiring mathematicians.

5. Conclusion

The authors have discussed some of the reasons why students might question whether they belong in the mathematics community. These are complicated issues and the authors do not claim to have solutions. However awareness of the feelings of doubt that students might have, and the factors which might make them feel that they are outside, and perhaps not welcome in, the community, will help tutors to present mathematics inclusively and to encourage their students to think of themselves as genuine mathematicians.

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