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.

Volume 23 No. 3. ***Special Issue: CETL-MSOR Conference 2024***

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This journal is published with the support of the **sigma** network and the Greenwich Maths Centre.

EDITORIAL

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In August 2024, delegates from across the globe gathered at the University of Limerick (Ollscoil Luimnigh) for the annual CETL-MSOR conference, and this edition of MSOR Connections is dedicated to sharing a collection of ideas, issues, solutions and opinions on the teaching, support and assessment of mathematics and statistics, that were presented at that conference. Themes covered at the conference included Linking research and practice in mathematics and statistics education in Higher Education, Teaching mathematics for mathematics specialist and non-mathematics specialist groups, The changing nature of mathematics and statistics learning support, and Exploring the affective domain in third-level mathematics and statistics education

This edition starts with five articles that address issues associated with studying mathematics when transitioning to higher education. The first is a case study by Banks which describes the design of a credit-bearing module at the University of Liverpool aimed at supporting students in the transition from school to studying mathematics at undergraduate level. This is followed by another case study by Ahmed and August describing an initiative introduced at the University of Glasgow to ease the transition into university-level mathematics and promote student engagement. These two case studies are then followed by three research articles, the first of which by Curran et al., investigates if issues which cause students difficulty with mathematics are present for students beyond their first year of university, focusing specifically on issues that undergraduate engineering students at an Irish university have identified as causing them difficulty when studying mathematics. Ryan and Fitzmaurice then investigates mathematics anxiety among out-of-field secondary teachers enrolled in Ireland's Professional Diploma in Mathematics for Teaching (PDMT), discussing ways to reduce mathematics anxiety amongst future PDMT students. The final article in this first group of five, by Brignell et al., then explores whether students hold stereotypes about academic staff, and whether this results in negative consequences for students and creates barriers to learning mathematics, discussing steps that staff can take to address these barriers.

The edition then presents three articles that explore issues associated with supporting and facilitating student learning in the mathematical sciences in higher education. The first of these is a research article by Mackenzie and Ahmed, which describes the "The Hub", a large maths and stats support centre at the University of Glasgow, exploring trends in the impact of engagement in maths support on students' final grade, as well as identifying gaps in students' knowledge. This is followed by an article by Steele which discusses different models for the provision of maths support, providing some background around how this is undertaken at the University of Manchester. The third and final article in this group by Mair et al. reports on the development and outcomes of a workshop focused on improving the accessibility of maths for visually impaired people, held at the University of Glasgow in 2024.

We then have a series of four articles that present opportunities through learning and assessment for developing students' confidence and communication skills with mathematics as well as their employability skills. The first by Russell is a case study that showcases an extra-curricular activity involving a large local employer and offered to undergraduate mathematics students at the University of Liverpool in 2024. This challenged students to work in groups with the aim of developing confidence in their skills and a greater awareness of the opportunities for mathematics graduates.

This is followed by a research article by Jones et al. describing opportunities for students at the University of Middlesex to work as mathematical ambassadors and to apply skills in communicating mathematics during a range of outreach and public engagement events. This explores the impact on increasing confidence and knowledge of mathematical topics, as well as enhancing their employability, communication skills, and social capital. Hobson et al. then presents a research article, which reports on a new assessment strategy for students on the Mathematics, Physics and Engineering integrated Foundation Year programmes at the University of Lincoln. This used group-work and co-created industry contexts in assessments and explores the impact this has had not just on attainment but also attendance and students' sense of belonging. This is followed by a second research article by Jones et al., which considers how authentic mathematical activities (i.e. the kind of tasks a maths graduate can expect in the workplace) are incorporated into the design and delivery of undergraduate programmes at Middlesex University. This discusses the implementation, benefits, and challenges involved and the effect on students' perceptions of mathematics. One of the authentic assessment contexts considered involves students' use of Generative AI as an aid to solving mathematics problems and as an aid to developing means of communicating results such as through animations.

The use of Generative AI as an assistive tool to improve productivity is also the theme of the final article which concludes this edition. This is a case study by Manning, which describes an approach to creating step-by-step draft maths solutions using Generative AI, which are then reviewed and corrected. In particular, ChatGPT is used and the article highlights the strengths and limitations of using ChatGPT for this purpose.

Finally, we would like to say thank you to all these authors for sharing their work. *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. However, just as important are the many reviewers who continue to contribute hugely to the sharing of this good practice and experience, but often go unacknowledged – thank you too for all your support for the journal. We can all help with the functioning of the journal 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

Affections in the transition to undergraduate mathematics

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Abstract

The module 'Introduction to Study and Research in Mathematics' is a credit-bearing unit of teaching designed particularly with the aim of supporting students in the transition from school to studying mathematics at undergraduate level in the UK. This case study discusses how the design of the module was impacted by consideration of the affective domain, aiming to build both students' understanding of and interest in mathematics as an academic discipline and their confidence in tackling mathematics questions they do not initially know how to answer.

Keywords: secondary-tertiary transition, affections, space to fail, comfort zone.

1. The importance of considering affections

Since I first read it, the following statement has had an ongoing impact on how I think about teaching maths.

> *"Three factors influence how effective your mathematical thinking is:*
>
> *your competence in the use of the processes of mathematical enquiry;*
>
> *your confidence in handling emotional and psychological states and turning them to your advantage;*
>
> *your understanding of the content of mathematics and, if necessary, the area to which it is being applied.*
>
> *… a knowledge of mathematical content … usually hogs the space. Often it is presented as the* ***only*** *important factor …" (Mason, et al., 1985, pp. 146-147).*

This resonated with my personal experience. I cannot recall any instance in my mathematical education that addressed the idea that I, as the one doing the maths, am a human being. Meanwhile, I had seen the impact of emotions and attitudes on students' performance. One particular group I taught told me repeatedly *"you have to be (the top student in the class) to do this".* Assuming a task is beyond you can become a self-fulfilling prophecy.

Di Martino, Gregorio and Iannone (2023) surveyed mathematics education literature between 2008 and 2021 related to the secondary-tertiary transition. They found that the discussion has become increasingly holistic, rather than focusing solely on cognitive aspects, but with consideration of affective elements still under-represented.

More recently, Geisler, Rolka and Rach (2023) modelled the extent to which measures of affect in mathematics undergraduates at the start of and later in their first semester correlated with those who had left their programme by the start of second year, whether voluntarily or not. They concluded that:

"students' interest in university mathematics as well as their mathematical self-concept was associated with less risk to drop out … [Also,] it seems plausible that increasing interest in university mathematics as well as increasing self-concept [over time] go along with less risk to drop out" (pp. 47-48).

Here the term 'self-concept' denotes how the students view their mathematical abilities. Next, the authors used qualitative methods to pinpoint incidents that impacted students' self-concept (p. 48). They found that:

"activities … like conducting proofs or working with definitions were mentioned more often than concrete content … It seems that these activities are a hurdle for students, which influences their self-concept independent from the specific mathematical content" (pp. 48-49).

They also highlight a comment from one student who *"indicated that he felt uncomfortable to have to ask the teaching assistant for help"* (p. 51).

The transition from school to university mathematics brings numerous changes for students; a good summary is given in (Geisler & Rolka, 2021). In the UK, by the start of university many students have experienced an extended duration in which their expected future identity is as a mathematics graduate. Consciously or otherwise, they are likely to have invested emotionally in this future self. Discovering a new style of mathematics brings into question their earlier decision to study maths. Those who continue their programme must adjust intellectually to the new approach required from them but should also adapt their self-image to account for the change. This can be an emotionally painful process.

My thinking took a step further while reading about teacher education. One thing a trainee teacher needs to learn is how to cope with being responsible for a class of children. Lecturing is not a suitable teaching approach for this skill. The learning required is affective, not cognitive, and can't be acquired from third-hand or even second-hand experiences; first-hand lived experience is needed. The same is true for the affective aspects of studying mathematics. This mindset was one of the cornerstones when I designed the module 'Introduction to Study and Research in Mathematics' (denoted in this case study by ISRM).

2. The module

ISRM is a module taken by the first-year students on our main mathematics undergraduate programmes in semester 1. That is, the module usually forms part of the transition from school to university mathematics; most students have recently completed UK secondary education. They take compulsory modules in a range of areas of maths in their first year, with an increasing selection of optional modules later allowing them to focus on their area of interest.

The syllabus has multiple foci. One part covers introductory aspects of the foundations of maths: informal logic, naïve set theory, numbers, functions and relations. Another part discusses the processes of engaging with university mathematics: reading mathematical texts; the role of definitions, theorems, proofs and examples; methods of proof; and 'writing up' mathematical arguments. A third strand aims to build the students' awareness of mathematics research and the wider academic community, while the final strand relates to careers and employability, particularly exploring the variety of roles open to mathematics graduates.

The class has in the order of 100 students and is taught over 12 semester weeks. In the initial implementation, each student had four weekly contact hours. The first hour took place in a lecture theatre and was fairly traditional in style. In 2020, all teaching activities moved online. This lecture was replaced by asynchronous teaching in the form of videos with 'quiz' questions built into them. It remained in this format after the return to in-person teaching.

The second hour was focused on active learning; the pace was controlled by the lecturer, but most class time was devoted to students attempting questions. The two-hour session at the end of the week was taught in smaller groups. Students were given a problem sheet to work through at their own pace, with lecturers, TAs and classmates available for discussion. The intention was for all these classes to take place in rooms where students could work together around tables. In practice, this was limited by the availability of suitable rooms on campus.

Additional 'background reading' resources were distributed through the VLE, comprising articles, videos and graphics on topics such as the nature of mathematics, biographies of high-profile mathematicians, and the axiom of choice.

There are two summative assessments for ISRM. One is an auto-graded assignment formed of short-answer questions completed using the Möbius online platform. The second assessment is a 'portfolio' of tasks completed over the course of the semester, with each task typically taking 1-2 sides of A4 paper. There is no time-controlled assessment for the module. Passing the module is a pre-requisite to progressing into the second year of study, but the grades do not impact the students' degree classifications.

3. The module survey

Late in academic year 2023-24, an online survey about ISRM was sent to all current students who had previously taken the module (between 0.5 and 3.5 years earlier). The objective was to learn about students' perceptions of the module following time to reflect on it in light of their later experiences. The flip side of this is that students might not recall details of the module accurately. Responses from some relevant survey questions are included below.

4. Ask A Tutor

One task the students must complete as part of their portfolio is named 'Ask A Tutor'. The instructions are as follows.

1. Read (Alcock, 2013) sections 10.1 – 10.5.
2. Talk to one of your university tutors/lecturers/advisor about some maths. This can be about any of your modules, or (if they are willing) about another area of maths, but it must not be solely related to problems sheets.
3. Write down details of the conversation:
    - who you spoke to;
    - when you spoke to them (give the date);
    - where/how you spoke to them;

    along with a short description (1–2 paragraphs) of the conversation and its context.

The book (Alcock, 2013) is essentially a handbook for mathematics undergraduate students. Sections 10.1 – 10.5 discuss the process of getting support from a lecturer, including how the student–lecturer relationship differs from the pupil–teacher relationship of secondary school. To these instructions, I added the following explanation of the purpose of the task. Anecdotally, adding this reduced the level of resistance from the students to doing it.

FAQ: Why do I have to do this? I don't want to!

The fact that students don't want to do this task is the reason we require it. Going to office hours is one of the best options for getting help with your studies. However, there is an emotional barrier to doing so. We want you to get over that barrier now, so that it's easier to go to office hours again later.

This task is not difficult in an intellectual sense. For many students, the hardest part is thinking of a suitable question to ask; some students ask to be told what to ask. However, for some students, such as those who experience social anxiety, completing the task as we would prefer it to be done is much more challenging. For inclusivity purposes, therefore, quite a lot of flexibility was given in completing the task, for example by contacting the lecturer via email. Allowing remote methods is also useful in the case of students resitting the module in the summer while off-campus. In practice many students opted to put minimal effort into completing the task. Tightening the requirements, with reasonable adjustments when needed, might be more beneficial for the cohort overall.

5. Research talks

In my experience, on telling someone *"I do maths research"*, the general public are often surprised that research in mathematics is possible. Some seem to conclude that I do sums with very big numbers. Those who studied more maths ask *"do you turn your paper sideways to fit your equations on?"* (Answer: occasionally).

Expecting undergraduates to understand the content of research mathematics is usually unrealistic. Nevertheless, we can familiarize them with the breadth, nature, aims, processes and environment of mathematics research. By default, mathematics graduates will function as ambassadors of the discipline to wider society. Doing so also enables them to make an informed decision about whether to join the research community themselves.

The main teaching activity in ISRM on this takes the form of 'research talks', where departmental lecturers present their research like in a research seminar but at a level suitable for the students. The talks are around 20 minutes in length, allowing two talks to fit within a one-hour class with time for questions. One purpose was to give the students more awareness of what the academics in the department are doing, to help them to feel part of the departmental community.

Two sets of two talks were scheduled a couple of weeks apart. The original reason for having the first class of the week in a lecture theatre was to provide a setting for these talks that mirrored that of academic research seminars. An alternative idea was to group the talks together to form a mini 'conference'; unfortunately, this did not fit well around other modules. More recently, we have used a mixture of in-person and online talks, reflecting the increased diversity in how research seminars now operate.

Besides considering the subject area of potential speakers, I invited lecturers to speak whom students would not have lectures with in their first year, incorporating diversity in career stage, gender and cultural background, to provide a range of different role models. Alongside describing their research, speakers were asked to discuss their day-to-day experiences as an academic and their career journeys.

Additionally, some of the ‘background reading’ resources were selected to provide insight into the research community. These include varied papers from undergraduate mathematics journals presented like research journals but with content accessible to first-year students. Other texts address the human side of mathematical community such as how our understanding of maths is impacted by gender, cultural background or disability.

The survey responses in Figure 1 suggest that a large minority of the students were conscious of these activities impacting their thinking.

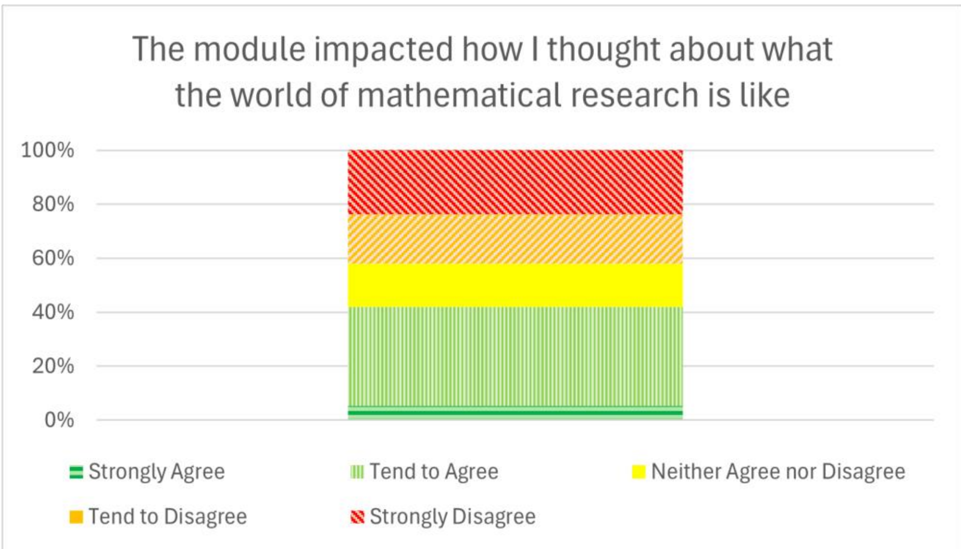

Figure 1: Survey responses on a 5-point Likert scale showing agreement with the statement 'The module impacted how I thought about what the world of mathematical research is like'.

This element of the module is assessed through a piece of ‘personal writing’ as part of the portfolio. This is a short piece of reflective writing (the instructions suggest ⅔ of a page), with the marking criteria set to reflect that this is a non-standard task for these students. The intention is for students to demonstrate that they have engaged with the learning materials and developed their thinking in some way, while also practicing their writing skills (other formats would be accepted, but I have not had any student choose to use one). This often causes contention; a number of students have asserted that *“I didn’t choose maths to write essays”.* Virtually all students will need to complete some similar form of writing later in life, for example when applying for jobs. Here they can practice a skill they are uncomfortable with in a low-stakes environment, rather than waiting until a time when succeeding matters more.

6. What does it mean to be a graduate mathematician?

When designing ISRM, I decided to encapsulate the syllabus using the question ‘what does it mean to be a graduate mathematician?’ That is, what does the process of becoming one look like during university, and what does being one look like after graduation, either in academia or in industry? It is important to have a coherent narrative, rather than giving the impression of the module being made up of ‘loose ends’.

The choice of the phrase ‘graduate mathematician’ was deliberate, taking into consideration the potential impact on the students’ sense of mathematical identity. There were two ideas I wanted to avoid communicating to students. One was the idea that those who stay in academia are ‘proper mathematicians’ while those who work in industry have in some sense ‘failed’. Mathematics has value in both settings, as shown for example by the requirements for the designation Chartered Mathematician (Institute of Mathematics & its Applications), and we want to encourage students to choose whatever career path is most suitable for them.

Consequently, I initially wanted the module careers activities to include a third set of ‘research talks’ from ‘mathematicians in industry’. In practice it proved too difficult to secure suitable speakers for this. Instead, we have had speakers a few years ahead of the current students, either those who have recently graduated from a mathematics degree or those who have completed a year in industry. This offers a different form of support for the students. Many students have chosen to study mathematics knowing that it keeps their career options open but with little idea of what direction they want to go. They are often consciously ignoring the looming threat of needing to begin career preparations. People who have recently been through similar experiences themselves can provide reassurance that, firstly, these students are not alone in feeling this way and haven’t shut off their options through inaction, and that, secondly, the process of finding suitable employment is not as overwhelming as the students fear it to be.

The second idea I wanted to avoid communicating to students was that they are not ‘mathematicians’. Many mathematics undergraduates will think of themselves as mathematicians. Academics may not agree, but communicating that disagreement to students will only serve to alienate them. Meanwhile, it is clear that mathematics undergraduates are not yet *graduate mathematicians* (except in very rare circumstances) but by joining the programme they have expressed a desire to become one.

7. Space to ‘fail’

The teaching approach used for the rest of the module syllabus mirrors that described in (Epp, 2003), except without formal logic. Aside from the ‘personal writing’, all module activities are ones we normally expect of students: reading mathematics; reading about mathematics; watching talks about mathematics; discussing with other students and lecturers; working with definitions and theorems; breaking down proofs to understand them; trying to prove/disprove mathematical statements; and writing up solutions. The primary differences from a ‘traditional’ maths course are that the questions presented to students require problem solving skills (rather than being exercises in following a taught method) and that the focus is on understanding the underlying ideas rather than relying on algorithmic approaches. For example, proof by induction is introduced through questions that use different base cases and step sizes, meaning the principle must be adapted to the context.

I describe the process of doing much school maths as like a train on a railway. At pre-defined points there are a few different directions you might select, but mostly you just keep chugging along doing the next step until you reach your answer. In contrast, tasks at university can be more like exploring a maze. You have a goal to reach, but you don't necessarily know how to reach it. Trial-and-error, arriving at dead ends, back-tracking and taking a new path to see where it leads are normal parts of the process; indeed, for research mathematicians they make up the bulk of the process.

The teaching of the module is intended to provide lots of time for students to practice this unfamiliar approach to maths problems, with lots of support available in real-time from classmates and teaching staff. Teaching staff aim to communicate that the value lies in developing skills rather than necessarily reaching 'the correct answer'. The 'Module Philosophy', which students are asked to read at the beginning of the module, finishes with the following.

> You should not expect to necessarily be able to complete all the activities for this module first time. Learning how to cope with that situation, and what to do when it happens, is a deliberate part of these activities. The assessment for the module is designed so that most of the activities do not directly count towards your mark, so that you have time to try, fail, and try again, without losing marks as a result. An important question to keep asking yourself is '**did I manage more this time that I did before?**'

Nevertheless, the survey results shown in Figures 2 and 3 suggest that students generally find the module challenging both intellectually and emotionally. Kiknadze and Leary state that *"people invoke the notion of comfort zone only when a behavior they desire to perform evokes anxiety because of potentially negative outcomes"* (2021, p. 2). Of the major categories of negative outcomes they identify, the only ones seemingly relevant here are unfavourable evaluations from either students themselves or those around them (module teaching staff and the other students sat with them in class).

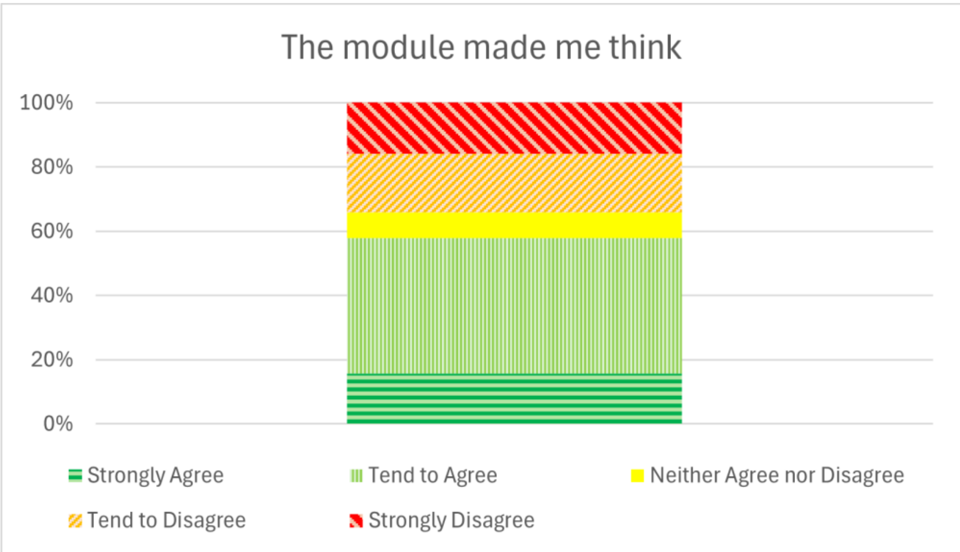

Figure 2: Survey responses on a 5-point Likert scale showing agreement with the statement 'The module made me think'.

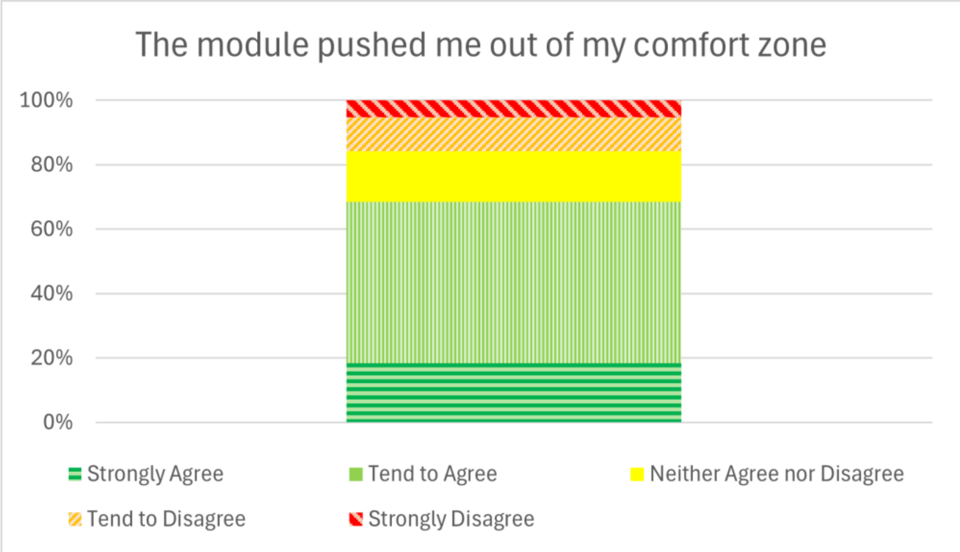

Figure 3: Survey responses on a 5-point Likert scale showing agreement with the statement 'The module pushed me out of my comfort zone'.

This perhaps mirrors the finding that the main reason surveyed students gave for not completing formative assessments was *"fear of failure"* (Finch, 2024). In contrast, the MSOR Subject Benchmark Statement says that, by the time they graduate, students are expected to have *"the ability to work independently with patience and persistence, pursuing the solution of a problem to its conclusion"* (QAA, 2023, p. 22).

8. Concluding reflections

ISRM was designed to provide students with a well-supported, low-stakes environment in which to practice skills that are central to their chosen field of study. Students who take advantage of the support available seem to value the rewarding sensation that results from hard-won insight.

However, a noticeable proportion of the students dis-engage from the module. It is unlikely that any mathematics student would have neither need nor desire to discuss at least part of the module content. On the face of it, these students therefore either:

- do not see developing these skills as sufficiently valuable to justify the effort required;
- are too afraid even with the level of support offered here;
- or are under too much time-pressure to pursue their studies properly.

In the first two cases, what can we do to mitigate these issues? To what extent is it in our power to do so, given that affections are not always rational? Should we accept the status quo?

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CASE STUDY

Using pre-sessional resources to provide academic support and improve transition to university-level mathematics

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Abstract

This case study gives an overview of an initiative introduced at the University of Glasgow to ease the transition into university-level mathematics and promote student engagement. Beginning in the academic year 2023/24, this took the form of pre-arrival maths resources sent to incoming students which were designed to bridge the gap between Higher and Advanced Higher[1] entrants to first year. This included videos and practice questions to help them improve their skills and further introduced them to the maths support available during their studies. We will discuss the changes made since the introduction, as well as planned future changes based on informal feedback and lessons learned from this experience.

Keywords: Transition, pre-arrival, mathematics, engineering, maths support.

1. Introduction

It has been recognised for some time that students are entering university ill-equipped in terms of their mathematical skills despite having achieved good grades at Advanced Higher/A level. Dubbed the ‘Mathematics Problem’ by a 1995 report (LMS, 1995), this has been an ongoing challenge faced by mathematics educators and support staff, which is believed to have several contributing factors (Lawson et al, 2019, p.1227-1228). These include changes in the mathematical competencies of school leavers over time (Lawson, 2003 and Hodds et al, 2020) and much larger and more diverse student cohorts with varying prior qualifications.

The problems have become more apparent post-pandemic with studies showing that learning loss during the pandemic seemed to be greater for mathematics than for literacy (Ofqual, 2021). Students entering one UK university in 2021 performed significantly worse in entrance diagnostic tests than those the year before (Hodds, 2023), and there were disappointing maths exam results seen across several cohorts at the University of Glasgow in 2022/23. While some of this can be attributed directly to loss of learning time and changes in curricula (e.g. topics being removed from the Higher and Advanced Higher Maths curricula), other factors are thought to include the effects of the pandemic on student engagement more generally. There have been numerous news articles about the lack of

[1] Scottish Qualifications Authority (SQA) Highers and Advanced Highers are the standard qualifications for entry into higher education in Scotland. Highers are typically taken in the penultimate year (age 16-17) and Advanced Highers are taken in the final year (age 17-18) of secondary education.

attendance at university lectures since the pandemic (e.g. (Otte, 2024)), and an anecdotal lack of engagement has been noted amongst maths support practitioners.

Whatever the reasons, the cumulative nature of learning mathematics and the impact of self-efficacy on mathematical performance (see e.g. Cameron, 2024), mean that gaps in knowledge and a lack of confidence with fundamental skills will significantly hinder a student's progress. This motivated the creation of a resource that would allow students to ensure that the required underpinning knowledge is in place before they begin their studies, or at least as early as possible. This, along with the hope that engaging students early would lead to better engagement throughout their studies, led to the idea of the pre-arrival resources described in this case study, which are aimed at students on the two largest first-year maths modules at the University of Glasgow, namely Mathematics 1 and Engineering Mathematics 1.

In the remaining sections, we give a more detailed background of the modules we hoped to support, describe the pre-arrival resources produced and then discuss the outcomes of our work.

2. Mathematics 1 and Engineering Mathematics 1

2.1 Mathematics 1

The University of Glasgow has a College-entry system where students study three subjects in their first year. Mathematics 1 is the compulsory maths module for students on Mathematics, Statistics and Physics degree programmes. In addition, many other students take this module as an elective making it a very large cohort of up to 750 students.

University recruitment policy in Scotland means that, although most students taking Maths 1 will have at least a B grade in Advanced Higher Maths (or equivalent, such as A level), there are also a good number of students presenting with only Higher Maths - the maths course generally completed in the penultimate year of school in Scotland. Students with only Higher Maths will clearly have a gap in knowledge compared to those with an Advanced Higher qualification, e.g. Higher Maths students will not have seen complex numbers. To help bridge this gap, the School of Mathematics & Statistics introduced a 'Core Skills' component to the Maths 1 module when it was revised six years ago.

Core Skills covers five topics to reflect the differences between Higher and Advanced Higher Maths. These are: (1) Differentiation; (2) Integration; (3) Complex Numbers; (4) Binomial Theorem and Induction; (5) Matrices and Vectors. There is a test for each topic, and all students, including Advanced Higher entry students, are required to pass all five tests (pass mark 75%) before the end of the academic year. Students are given numerous opportunities to take the tests and can sit each test as many times as they need. A lecture is scheduled during semester 1 for each of these topics, which aligns with when the topic is needed for the main part of the Maths 1 module.

2.2 Engineering Mathematics

The Engineering students at the University of Glasgow follow a separate mathematics curriculum to other STEM students. They have two compulsory maths modules, Engineering Mathematics 1 and Engineering Mathematics 2, which are taken in first and second year respectively. Engineering Maths 1 covers topics such as functions, calculus, matrices, complex numbers and vectors, and has a significant overlap with Advanced Higher Mathematics. Engineering Maths 2 covers multivariable calculus, differential equations, Fourier series and Laplace transforms. Both are large classes, with approximately 400-500 students.

As part of Engineering Maths 1, students sit a maths diagnostic test in their first week at university and are also required to pass five ‘100%’ tests in the first semester, which take place online and are designed to focus on foundational skills. Support for these tests, as well as for the overall module, is provided by optional maths drop-ins run by Student Learning Development (where the centralised maths support service sits). However, there has been a stark difference in attendance at these drop-ins pre- and post-pandemic.

Anecdotal evidence from lecturers and support staff suggests that, despite the efforts made in Engineering Maths 1, there are numerous students in Engineering Maths 2 who are still struggling with their foundational skills – specifically with general algebraic manipulation, sketching graphs such as straight lines and parabolas, and basic differentiation and integration. Without being addressed, this can lead some students to underperform in Engineering Maths 2, also affecting their progression to third year.

3. Pre-arrival initiative

3.1 Undergraduate Mathematics Pre-enrolment Moodle

Once the semester is underway, the Core Skills tests can get forgotten by students amongst all their classes, labs and assignments. Since these skills are important for students to understand the content of their Maths 1 lectures, it was felt that it would be useful to engage students with Core Skills earlier and take advantage of freshers’ enthusiasm. As such, a pre-arrival resource based on the Core Skills component of Maths 1 was planned and prepared. As students are not able to access the University VLE (Moodle) prior to registration and enrolment, the resource was hosted on the University of Glasgow’s External Moodle, which anyone can create an account for. Students were sent out details on how to sign-up, including an enrolment key, in late August, giving them a few weeks before semester to look over the resource.

The pre-arrival course consists of:

- A welcome message to the School of Mathematics & Statistics alongside introductory information about Core Skills and a welcome video message from the member of staff responsible for Core Skills;
- A section dedicated to each Core Skills topic with links to external resources (mainly Khan Academy) as well as a forum for students to be able to post any topic-related questions;
- Information relating to maths support and other support services at the University including a welcome video by the Maths Adviser (from centralised support service) and the Hub Coordinator (in-house drop-in maths support);
- A small set of sample questions similar to those in the actual Core Skills tests (see Appendix).

The plan was to not just initiate the students into the Core Skills component but also to foster a sense of belonging by welcoming them to the university and giving them an opportunity to meet each other and as such, a forum was set up for this purpose.

We offered online drop-in sessions after the resource had been sent out in case students had questions relating to the material, and then in-person drop-ins during orientation week. We deliberately avoided giving answers to the sample questions, encouraging students to attend the support sessions if they had any doubts.

3.2 Mathematics Support & Advice for Year 1 Engineers Moodle

In the process of creating the pre-arrival Moodle for Mathematics 1, it was suggested that a similar resource would be beneficial for incoming Engineering students. Several of the goals remained the same; namely welcoming students to the university, building their confidence with foundational skills and encouraging them to engage with maths support right from the beginning of their studies. However, there were a couple of differences in the cohorts that we felt should be considered:

1. Engineering Maths 1 does not have the equivalent of the catch-up lectures offered as part of Core Skills, so it seemed important to provide asynchronous resources to help students act on the results of their maths diagnostic test;
2. Since the overlap between Advanced Higher Maths and Engineering Maths 1 is considerably greater than with Maths 1, we felt the content for Engineers should focus more on the foundational skills second year students were seen to be struggling with.

In addition, many Engineers are unaware quite how important maths will be to their studies (Harris et al., 2015), so we felt this was an excellent opportunity to highlight this early on.

In 2023, there was insufficient time to adapt the Moodle created for Maths 1, so only minor modifications were made. This included adding a new topic called ‘Maths Essentials’, which covered algebraic manipulation, trigonometry, straight lines and quadratics, and removing more advanced topics like proof by induction. Additionally, a set of practice questions and solutions was added to each topic, so that students could check their understanding of the video content (either while preparing for the diagnostic test, or when going back to review topics afterwards). Only numerical answers were given, as students were encouraged to attend the maths drop-ins if they had any queries. This was sent out to incoming students by the School of Engineering’s Teaching Office in early September, just a couple of weeks before orientation week.

For 2024, there was more time to make changes and to receive valuable input from staff within the School of Engineering. This led to the addition of a welcome video from the School’s Learning & Teaching Convener emphasising the importance of maths in Engineering, as well as a ‘Meet the Lecturers’ section where students could see videos from several of the lecturers they would meet on their course.

Discussion with the module lecturers also led to a decision to further restrict the content on the Moodle to the fundamental skills; for example, removing the topic on complex numbers (which they have a whole block on during the module) and instead expanding other topics such as sketching graphs. We added a short (5 questions) interactive quiz to each section, so that we could assess engagement more easily and, more importantly, students could quickly assess whether they should spend time looking at that topic. Students did not receive answers to the questions they got wrong in these quizzes, just directions on which videos to watch or a suggestion to attend the maths drop-in sessions. We additionally expanded the range of videos (still curated rather than created due to time constraints) and practice questions (see Appendix), with each practice question also mapped to the relevant video(s). Finally, we ensured that some of the questions had an engineering focus to them, as students sometimes cite the perceived lack of relevance of the maths they are learning as a barrier (Harris et al., 2015).

4. Outcomes and Discussion

4.1 Dissemination

In an ideal world, we would like incoming students to have access to the relevant Moodle early in the summer, so that they have plenty of time to work through the resource if they choose to. However, the nature of university admissions makes this impossible since offers are not confirmed until after the students receive their exam results. For A level students, this is not until mid-August which means that the resource cannot be sent out until after then.

The other challenge we face is identifying all the relevant students who should receive access to the Maths 1 pre-arrival Moodle. Although we had a list of all the students who have Maths 1 as a compulsory module (i.e. Mathematics, Statistics and Physics students), many other students take Maths 1 as an elective. These students will not make this choice until after they are enrolled, which may not happen until orientation week, or sometimes even later. We took the approach of sending it to students on degree programmes from which students often choose maths as an elective (e.g. computer science, economics and chemistry) hoping that this would reach most students. This was not an issue for the Engineering Maths 1 Moodle, as it is only Engineering students who take this module.

For 2023/24, the sign-up information for the Moodle resource was sent to students multiple times via email, but despite this, over half the students who later gave feedback about the resources stated that they did not know it existed. The same approach received a similar response the following year, but other options for reaching students before term begins are limited. However, for 2024/25, we additionally displayed a QR code for the Engineering Maths Moodle at the students' induction session in orientation week. While this no longer counted as 'pre-arrival', it was highly successful in getting students to sign-up and ensured that they had the resource to prepare for, and more importantly review, the diagnostic test the following week.

4.2 Engagement

For the academic year 2023/24, we had approximately 160 students sign up to the pre-arrival Moodle for Maths 1, and approximately 220 for the Engineering version. For 2024/25, the numbers increased to approximately 200 and 360 respectively, with the significant increase in Engineering numbers due solely to displaying the QR code at their induction event.

In September 2023, attendance at the online drop-in session for students enrolled on the Maths 1 pre-arrival Moodle was very low, and the few questions asked were concerned more with enrolment and registration than the mathematical content of the sample test. Attendance at the in-person session in orientation week was good and students were keen to get their work checked and ask any questions relating to the sample problems. For this reason, it was decided to remove the online support session in September 2024 and run two in-person drop-in sessions instead.

In addition, a board games session was organised to take place in the same classroom at the end of the second drop-in session, and the Maclaurin Society (the students' Maths Society) were invited to attend as well. The inclusion of a fun social event proved popular and twice the number of students were in attendance compared to the session that took place earlier in the week.

A small number of students posted a short message on the 'general' forum on the Maths Moodle, introducing themselves and adding which course they were planning to pursue at Glasgow. It would be good to have more students participating in informal chat on this forum, so students will in future be encouraged in their email invitations to post an introduction message.

For the Engineering students, attendance at the first-year maths drop-ins that take place throughout the year has remained low in both 2023/24 and 2024/25. However, we have seen an improvement in attendance at Engineering Maths 2 drop-ins in 2024/25, which corresponds to the students who received the first pre-arrival Moodle. We have yet to establish the cause of their change in engagement between first and second year, but we feel that it warrants further investigation.

Adding interactive quizzes to the Engineering Moodle this academic year has made it easier to track engagement, and we hope to be able to use this information in the future to establish whether there is any correlation between early (or continued) engagement with the pre-arrival resource, and final results in Engineering Maths 1 and 2.

4.3 Core Skills Results

Despite student numbers staying relatively constant, the total number of tests passed (score greater than or equal to 75%) by December 2024 is 3297 which is a dramatic increase compared to the number of passes at same time over the last two years: 1776 and 1643 tests passed in December 2023 and December 2022 respectively. Reminder emails are sent to students, but the frequency and timings of these have remained unchanged.

4.4 Informal Feedback and Future Plans

On the Maths Moodle, the most popular topics were ‘Complex Numbers’ and ‘Vectors & Matrices’, which is perhaps not surprising given these were the topics that were given less time, or left out of the syllabus entirely, during the Covid period (Price et al, 2022). Interestingly, ‘Differentiation’ was also one of the more commonly revised sections.

On the Engineering Moodle, the most popular topics were ‘Algebra’ and ‘Vectors’. Again, seeing ‘Vectors’ amongst the popular topics is not surprising, but it was interesting to see ‘Algebra’ (which included rearranging equations, functions, quadratics and inequalities) there too – this could simply be that it was the first topic listed on the page, or it could indicate that students are already aware this is something that they need to work on.

Generally, the students who enrolled on either Moodle reported finding the resource very helpful, with a consensus that it was nice to know what was expected of them, and that they would recommend the resource to others. For 2023/24, the most commonly requested change was for there to be more practice questions and worked examples available. While this theme remained in the feedback for the Maths Moodle in 2024/25, the addition of more questions and interactive quizzes to the Engineering Moodle resulted in these now most commonly being cited as something they liked about the Moodle. We hope to expand on this for future years, adding more interactive quizzes, and perhaps also linking to the Helping Engineers Learn Mathematics workbooks (HELM Project, 2015), so that they are aware of this excellent resource early in their studies.

Some of the comments we received indicated that students were confusing the pre-arrival Moodle resource with the one currently in use for Maths 1. For this reason, feedback was sought earlier this academic year, but the confusion seems to have persisted. Other students reported the disconnect between the pre-arrival Moodle and their current Moodle pages (namely, that they have to login to a separate place to find the pre-arrival resource) is something they would like changed. This is not possible given the nature of the External Moodle, but we will consider making a copy of the

Engineering Moodle available on the internal Moodle, so it is easier to access once teaching begins. This is not necessary for the Maths Moodle, since there is already a Core Skills Moodle in place.

Finally, we are keen to address the fact that there are still many students on both modules who did not enrol on the relevant pre-arrival Moodle. As discussed above, the most cited reason for this was that they simply didn't know about the Moodle. However, it was also common for students to say they had not enrolled because they were already confident in their maths ability. Despite making an effort to remove any language indicating this was a remedial resource, this theme persisted the following academic year. It would be interesting in future to investigate whether there is any evidence to show future likeminded students that they could still benefit from engaging in the resource.

5. Acknowledgements

The authors would like to thank Dr Andy Wand, Head of Core Skills, School of Mathematics & Statistics and Mr Greg Burgess, School Retention & Success Lead, College of Science & Engineering, who were part of the team that made this project possible.

6. Appendix

6.1 Practice questions from Mathematics 1 Pre-enrolment Moodle

1. Consider the following function:

$$f(x) = 2\ln(x-3)$$

   (a) Sketch the graph of f.

   (b) What are the domain and range of f ?

   (c) What is the x-intercept of the graph of f ?

2. Write the complex number $-9+9i$ in form $r(\cos\theta + i\sin x)$ where r is a non-negative real number and $0 \le \theta < 2\pi$.

3. Let a, b, and d be integers. The following statement:

   If the product ab is divisible by d, then at least one of a and b are divisible by d.

   is false. Provide a counterexample of integer values for a, b and d to prove this.

4. Find

$$\int_0^{10} f(x)dx$$

   where

$$f(x) = \begin{cases} 8 & \text{if } x < 8 \\ x & \text{if } x \ge 8 \end{cases}$$

   (In other words, f is the function which returns the constant value 8 for all x less than 8, and returns x for all x greater than or equal to 8).

6.2 Example of Topic Questions Engineering Maths 1 Pre-enrolment Moodle

Quadratics

University of Glasgow

If you get stuck with any of the following questions, try taking a look at the corresponding video on the Moodle page - the relevant video(s) are indicated in brackets after the question number.

You may find it helpful to start by watching **Video A** to get used to the terminology surrounding parabolas.

1. **(Video B)** Expand the brackets in the following:

a. $(x+3)(x+2)$

b. $(x+4)(x-4)$

c. $(x+4)^2$

d. $(2x+4)(x-1)$

e. $(4x-5)(3x+12)$

f. $(x+1)(x+2)(x+3)$ (actually a cubic instead of a quadratic)

5. **(Video G)** Complete the square, i.e express each quadratic as $y=\alpha(x-\beta)^2+\gamma$:

a. $y=x^2-4x+2$

b. $y=x^2-4x-4$

c. $y=x^2+6x+4$

d. $y=x^2-x-1$

e. $y=x^2+3x+4$

f. $y=4x^2-16x-16$

6. **(Videos E and A)** An object is thrown from the top of an 88.2m building (approximately the height of the Gilbert Scott Building at the University of Glasgow), at a speed of 14.7 metres per second. The height from the ground t seconds after being thrown is given by the quadratic equation

$$y=-4.9t^2+14.7t+88.2.$$

After how many seconds will the object hit the ground? And what is the maximum height it will reach?

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RESEARCH ARTICLE

Factors affecting first, second and third year undergraduate engineering students' perception of their mathematics modules

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Abstract

It is well documented in the literature that students entering their first year of university struggle with adapting to the new teaching style and environment. This is particularly evident in the literature among students enrolled in STEM courses at university, including those enrolled in engineering courses. One of the primary concerns around students entering engineering courses in university is their level of mathematics and its subsequent effect on their learning. The issues identified in the literature focus on students in their first year of university but this neglects students in later years who may also experience issues. Therefore, in this paper, we investigate, through survey responses, if issues which cause students difficulty are present for students beyond their first year of university. Specifically, we report factors that first, second- and third-year undergraduate engineering students at an Irish university have identified as causing them difficulty when studying mathematics. Moreover, we investigate what, if any, impact these issues may have on students' perception of mathematics and their stress levels due to mathematics.

Keywords: Engineering Mathematics, mathematics problem, higher education

1. Introduction

Students around the world who are entering universities and studying service mathematics (e.g., engineering, technology, business, science students) have exhibited a declining mathematical ability with this phenomenon being referred to as the *Mathematics Problem* (Lawson, 2003). The *Mathematics Problem* was first identified in the United Kingdom (Society, 1995) where, in the 1980s, academics across the UK noted higher drop-out rates from universities and lowering academic performances among university students. This idea remained speculative until the Engineering Council published a report in 2000 confirming the academics' suspicions (Hawkes and Savage, 2000). Further research solidified the idea that students' mathematical standards were dropping and furthermore, the *Mathematics Problem* was identified in other countries such as Ireland (O'Donoghue, 1999), Australia (Matthews Kelly et al., 2012) and across Europe (Alpers, 2008).

One key aspect of the *Mathematics Problem* is shallow content knowledge, which can lead students to struggle with learning mathematics in university - where the mathematics is generally more difficult than in secondary school and often requires more abstract thinking. This "abstraction shock" (Hefendehl-Hebeker, Ableitinger and Hermann, 2010) can cause significant strife for students, even those considered to be mathematically strong in secondary school (Di Martino and Gregorio, 2019).

Aside from lacking mathematical fortitude, students report facing other issues - namely those under the theme of "teaching style". There is a distinct disconnect between the way teaching is carried out at second-level and at third-level (Brandell, Hemmi and Thunberg, 2008). Moreover, students usually receive more guidance at second-level and may struggle to become autonomous learners (Wingate, 2007). There is also evidence that teachers at third-level lack knowledge of good pedagogical practice (Murtonen and Vilppu, 2020) which may lead to poor teaching strategies (Knight, 2002). This can manifest in teachers covering material too quickly or not properly assessing their students' prior knowledge. Moreover, teachers often do not emphasise the relevance of the material they are teaching, leading to low student motivation (Taleyarkhan, Lucietto and Azevedo, 2021). In recent years, students have also had to contend with the impact of the COVID-19 pandemic on education. In particular, students who were at the end of their second-level education (so students who graduated from second-level in 2020 and 2021) during the pandemic were impacted negatively in several countries, including Ireland (Thorn and Vincent-Lancrin, 2022).

The issues students face when they enter university from secondary school have been described in the literature by the secondary-tertiary transition (STT), which includes not only the cognitive and didactical issues mentioned above but also those that are socio-cultural in nature (Gueudet, 2008), i.e., those which derive from the difference in culture at university and secondary school. Naturally, the STT has been studied in the context of students in their first year of university, however in this paper, we investigate if these issues are present in students beyond the first year of university. Furthermore, we report on how these issues impact the students' perception of their mathematics modules.

The research question addressed in this paper is as follows: *What are the factors affecting undergraduate engineering students': (i) confidence in, (ii) perception of difficulty of, and (iii) stress levels relating to, their mathematics modules in first year of university and beyond?*

2. Methodology

2.1. Sample

The sample for the study in this paper consisted of $n = 100$ undergraduate engineering students enrolled in first, second and third year (of a four-year degree) at an Irish university. The students range in age from 19 to 22 years old and are spread across eight different courses (all variants of engineering courses). Students complete either four or five (depending on their specific course) Engineering Mathematics modules within the first three years of their undergraduate degrees. We note that the Engineering Mathematics modules completed by the students of engineering degrees in this study are recognised as containing core mathematics topics for undergraduate engineers worldwide (SEFI mathematics working group, 2002).

We give some detail regarding the topics covered in each of the Engineering Mathematics modules taken by the students. We believe this will add some context to the discussion later.

- Engineering Mathematics 1 (EM1): Differential calculus, Series, Vector algebra
- Engineering Mathematics 2 (EM2): Integral calculus, Ordinary differential equations, Functions of several variables and partial differentiation, Matrices
- Engineering Mathematics 3 (EM3): Laplace and inverse Laplace transforms, Fourier series, Linear algebra
- Engineering Mathematics 4 (EM4): Probability and Statistics
- Engineering Mathematics 5 (EM5): Vector calculus, Partial differential equations, Numerical methods.

In Table 1, we provide relevant biographical information pertaining to the students in our sample. To interpret rows 4 and 5 of Table 1, we provide a short account of the Irish education system. Students take six years of second-level education in Ireland with fourth year, called transition year, often being optional. At the end of second-level, students take the Leaving Certificate examinations, in which they sit examinations in a minimum of six subjects. Mathematics is taken by almost all of the students. Students receive grades in each subject with H1 being the highest attainable grade. Students' grades are converted into points (with 625 being the maximum achievable) and these points are used as entry determinants to third-level courses in Ireland. For the subject of mathematics, there are five strands that students cover throughout their second-level mathematics studies: Statistics and Probability, Geometry and Trigonometry, Number, Algebra and Functions.

Table 1. Biographical information regarding students in the sample for this study.

Year	First Year	Second Year	Third Year
Responses (Total number of students enrolled)	49 (200)	35 (323)	15 (130)
Male/Female/Non-Binary	30/19/0	23/13/0	10/4/1
Mean Leaving Certificate Points (max. 625)	577	543	589
Median grade in Mathematics in Leaving Certificate	H2	H2	H2

A limitation of the study that we identify immediately is that there is a relatively low response rate, particularly among the third years. This is something we aim to improve upon in subsequent studies on this topic.

In 2021 (when the third years would have completed the Leaving Certificate), a score of 589 points renders the third years in the top 6.4% of students nationally in the Leaving Certificate results that year (Central Applications Office, 2025a). In 2022 (when the second years would have completed the Leaving Certificate), a score of 543 points had the second years in the top 16.8% of students nationally in the Leaving Certificate results that year (Central Applications Office, 2025b). In 2023 (when the first years would have completed the Leaving Certificate), a score of 577 points put the first years in the top 8.7% of students nationally in the Leaving Certificate results that year (Central Applications Office, 2025c). Moreover, in 2021, 12.9% of students nationally received either a "H1" or "H2" (the highest and second highest results) in their mathematics examination in the Leaving Certificate and in 2022 and 2023, 13.7% of students and 9.8% of students respectively did likewise (CareersPortal Leaving Cert Results Grades Explorer, 2025). From these results, we can conclude that the students in this survey can be considered mathematically and academically strong students, at least from the perspective of the grade achieved in the end of second-level examinations in Ireland.

2.2. Data Collection and Analysis

The data for this study was collected through responses to a survey consisting of thirty questions[1]. Biographical, Likert and open-ended style questions were present in the survey leading to quantitative and qualitative results. Having been granted ethical approval, two of the authors, who both work in the Mathematics Support Centre in the university where this study took place, informed the students about the survey during one of their Engineering Mathematics lectures (with prior permission from the lecturers). The students received a link to the surveys (Microsoft Forms) via email around the midpoint of the second semester of the 2023/2024 academic year (approximately mid-February 2024). The surveys remained available for the students to complete for a period of approximately one month. After segregating the data into quantitative and qualitative data files, the authors analysed the quantitative data using *R* and the qualitative data using inductive thematic analysis (Braun and Clarke, 2006). Due to the short nature of this paper, we only consider the responses to two of the open-ended style questions, the results of which are discussed in section 3.2.

3. Results

3.1. Quantitative Results

The students reported their level of agreement, on a scale from 1 (strongly disagree) to 5 (strongly agree), with the statements:

1. During my first year I was confident with mathematics.
2. I am confident with the mathematics I am studying now[2].
3. When I first started in university, I found maths difficult.
4. The maths I'm studying now is easy.
5. When I first started studying mathematics in university, it caused me significant stress.
6. My stress levels decreased after the first year.

We provide a master table of the results in Table 2.

Table 2: Master table showing the number and percentage of students who gave each type of response to each of the six statements.

Statement	Strongly Disagree Number (%)	Disagree Number (%)	Neutral Number (%)	Agree Number (%)	Strongly Agree Number (%)
1	1st Yr: 5 (10.2)	1st Yr: 12 (24.5)	1st Yr: 18 (36.7)	1st Yr: 10 (20.4)	1st Yr: 4 (8.2)
	2nd Yr: 6 (16.7)	2nd Yr: 14 (38.8)	2nd Yr: 9 (25.0)	2nd Yr: 6 (16.7)	2nd Yr: 1 (2.8)
	3rd Yr: 1 (6.7)	3rd Yr: 5 (33.3)	3rd Yr: 1 (6.7)	3rd Yr: 5 (33.3)	3rd Yr: 3 (20.0)
2	1st Yr: 6 (12.2)	1st Yr: 21 (42.9)	1st Yr: 12 (24.5)	1st Yr: 10 (20.4)	1st Yr: 0 (0.0)
	2nd Yr: 2 (5.6)	2nd Yr: 7 (19.4)	2nd Yr: 15 (41.7)	2nd Yr: 8 (22.2)	2nd Yr: 4 (11.1)
	3rd Yr: 3 (20.0)	3rd Yr: 5 (33.3)	3rd Yr: 3 (20.0)	3rd Yr: 3 (20.0)	3rd Yr: 1 (6.7)
3	1st Yr: 6 (12.2)	1st Yr: 13 (26.5)	1st Yr: 13 (26.5)	1st Yr: 13 (26.5)	1st Yr: 4 (8.2)
	2nd Yr: 2 (5.6)	2nd Yr: 3 (8.3)	2nd Yr: 10 (7.8)	2nd Yr: 12 (33.3)	2nd Yr: 9 (25.0)
	3rd Yr: 1 (6.7)	3rd Yr: 4 (26.7)	3rd Yr: 3 (20.0)	3rd Yr: 4 (26.7)	3rd Yr: 3 (20.0)
4	1st Yr: 18 (36.7)	1st Yr: 22 (44.9)	1st Yr: 8 (16.3)	1st Yr: 1 (2.1)	1st Yr: 0 (0.0)
	2nd Yr: 2 (5.6)	2nd Yr: 8 (22.2)	2nd Yr: 18 (50.0)	2nd Yr: 5 (13.9)	2nd Yr: 3 (8.3)
	3rd Yr: 7 (46.7)	3rd Yr: 5 (33.3)	3rd Yr: 2 (13.3)	3rd Yr: 1 (6.7)	3rd Yr: 0 (0.0)
5	1st Yr: 11 (22.4)	1st Yr: 17 (34.7)	1st Yr: 12 (24.5)	1st Yr: 4 (8.2)	1st Yr: 5 (10.2)
	2nd Yr: 1 (2.8)	2nd Yr: 10 (27.8)	2nd Yr: 5 (13.9)	2nd Yr: 12 (33.3)	2nd Yr: 8 (22.2)
	3rd Yr: 2 (13.3)	3rd Yr: 3 (20.0)	3rd Yr: 3 (20.0)	3rd Yr: 5 (33.4)	3rd Yr: 2 (13.3)
6	1st Yr: N/A	1st Yr: N/A	1st Yr: N/A	1st Yr: N/A	1st Yr: N/A
	2nd Yr: 7 (19.4)	2nd Yr: 8 (22.2)	2nd Yr: 8 (22.2)	2nd Yr: 9 (25.0)	2nd Yr: 4 (11.1)
	3rd Yr: 4 (26.7)	3rd Yr: 6 (40.0)	3rd Yr: 3 (20.0)	3rd Yr: 1 (6.7)	3rd Yr: 1 (6.7)

We now assign a numerical value to each response for the six statements above: “Strongly Disagree” was assigned 1, “Disagree” was assigned 2, “Neutral” was assigned 3, “Agree” was assigned 4 and “Strongly Agree” was assigned 5. By assigning each response a numerical value, we can provide the median and interquartile range response for each statement, for each year group. We provide this in Table 3 below.

Table 3: Median and Interquartile Ranges response for each statement for each year group.

Statement	Median (IQR) First Years	Median (IQR) Second Years	Median (IQR) Third Years
1	3(2)	2(1)	4(2)
2	2(1)	3(1.25)	2(1.5)
3	3(2)	4(1.25)	3(2)
4	4(1)	3(1)	4(1)
5	2(1)	4(2)	3(2)
6	N/A	3(2)	2(1.5)

A sign test showed that there was a statistically significant increase in the perceived difficulty of the mathematics module that the first year group were studying at the beginning of first year to the mathematics module they were studying at the time (in their first year) they completed the survey ($p < .001$). For the second year group, a Wilcoxon signed rank test showed that there was a statistically significant decrease in the perceived difficulty of the module from first year to the students’ point in time of their studies when they completed the survey ($Z = -2.520$, $p < .05$). For the third year group, a Wilcoxon signed rank test showed that there was a statistically significant increase in the perceived difficulty of the module from first year to the students’ point in time of their studies when they completed the survey ($Z = -2.801$, $p < .01$).

A sign test showed that there was a statistically significant decrease in the confidence level of the mathematics that the first year students were studying at the beginning of their first year to the mathematics they are studying now ($p < .01$). A sign test, and a Wilcoxon signed rank test showed that there was no statistically significant change in confidence in mathematics reported by the second or third years between the start of university and the time they completed the survey ($p=0.064$; $Z=-1.874$ $p=0.061$ respectively).

3.2. Qualitative Results

In order to address the research question, we only focused on the responses to two of the open-ended questions from the survey:

- Question A: For the module you selected as the most difficult in Question 22[3], was/were there any factor(s) that you feel significantly contributed to the level of difficulty and/or the level of stress that you experienced?
- Question B: Is there anything else you found challenging about studying mathematics in university?

We provide the results of our analysis of the responses to Question A in Table 4 and the analysis of the responses to Question B in Table 5.

Table 4. Major themes identified in responses to Question A.

As stated previously, EM1 refers to Engineering Mathematics 1, EM2 refers to Engineering Mathematics 2, etc. For example, in the first row 0/100/NA/NA/NA shows that of the 38.7% of the first-year students who mentioned something about 'problem with lecturer', 0% mentioned EM1, 100% mentioned EM2 and as these students are in first year, it is not possible for them to mention EM3 – EM5 so these are marked as NA.

Major Theme (% of students from sample who mentioned something under this theme)	Subtheme	Year groups reporting subtheme (% of each year group)	Percentage of students reporting each subthemes who mention each module: EM1/EM2/EM3/EM4/EM5* as the most difficult NA: Not Applicable
Teaching Style (67.0)	Problems with Lecturer (Lecturer speaking too quietly, hard to communicate with, etc.)	Yr 1 (38.7)	0/100/NA/NA/NA
		Yr 2 (32.3)	10/30/60/0/NA
		Yr 3: (15.4)	0/0/50/0/50
	General Mention of Teaching Style	Yr 1 (16.0)	0/100/NA/NA/NA
		Yr 3 (38.5)	0/40/60/0/0
	Poor/Confusing explanations given of material	Yr 1 (25.0)	0/100/NA/NA/NA
		Yr 2 (12.9)	0/25/75/0/NA
		Yr 3 (23.1)	0/0/67/0/33
Content (42.0)	Novelty of the material covered	Yr 1 (11.4)	0/100/NA/NA/NA
		Yr 2 (12.9)	25/0/75/0/NA
		Yr 3 (23.1)	0/67/33/0/0
	Quantity of material covered	Yr 1 (11.4)	20/80/NA/NA/NA
		Yr 2 (12.9)	25/25/50/0/NA
	Difficulty of the material covered	Yr 1 (18.2)	0/100/NA/NA/NA
	Lack of Application/Usefulness shown for material	Yr 2 (25.8)	0/25/75/0/NA

The two major themes identified in responses to Question A were teaching style and content, with subthemes under the former being reported by over two-thirds of respondents. The main factors reported by first-year students were the lecturer and poor/confusing explanations. The main factors reported by second-year students were the lecturer and a lack of application of the material. The main factors reported by the third-year students were poor/confusing explanations of the material and the novelty of the material. Aside from the novelty of the material, all three year groups report a factor relating to the teaching style employed by the lecturer as being the two main factors that contributed to the difficulty they experienced in the mathematics modules that they found most difficult.

Aside from this, we can see that the first-year students find EM2 more difficult than EM1, with all but one of the subthemes mentioned by the first-year students being unanimously made in relation to EM2. The quantity of the material was the only subtheme that was not unanimous with an 80-20 split in favour of EM2 being more difficult. The second-years report EM3 as being the most difficult with it garnering at least 50% of the vote for every subtheme. The third-years are more split among EM2, EM3 and EM5, with EM3 being mentioned in all subthemes and novelty being the only subtheme for which EM3 was not stated as the most difficult.

The main theme identified in the responses for Question B (see Table 5) for all three years was the change in teaching style when compared to secondary school. The first- and second-years also mention the abstraction of the material as something they found challenging, while the second-years identify the lack of examination material (such as previous examination papers and solutions) as an additional issue.

Table 5. Major themes identified in responses to Question B.

Theme	Year groups reporting subtheme (% of each year group)	Further Description
Teaching style change compared to secondary school	Yr 1 (41.7)	● A lot of learning is now self-directed ● Lecturer doesn't communicate as effectively ● Hard to ask questions in class since it is a bigger group
	Yr 2 (33.3)	● Learning is now self-directed ● Poor/Confusing teaching style ● Every lecturer has a different teaching style ● Lecture notes provided are poor
	Yr 3: (66.7)	● Poor teaching style ● Lack of an explanation ● Poor learning material
Lack of Exam Preparation Material	Yr 2 (20.0)	● Not being provided exam solutions ● Not being provided previous examinations ● Material in lectures being different to the exam
Abstraction of Material	Yr 1 (33.3)	● Material is more abstract than in secondary school ● Hard to get a full understanding of the reasoning behind the methods taught in the lectures
	Yr 2 (13.3)	● Mathematics is very abstract and doesn't correlate with other modules

4. Discussion

Throughout the rest of this paper, we provide quotes from the students. The quotes are in the form $XNTT$, where $X = \{A, B\}$ and indicates which question the quote corresponds to, $N = \{1,2,3\}$ and indicates the year the student who made the quote is in and TT is a unique two-digit ID number, randomly given to each student.

From Table 4 it is clear that teaching style is the main factor identified by the students in this study which causes them difficulty in their mathematics modules. The first-years report problems with the lecturer and poor/confusing explanations as the main two subfactors within "teaching style" which cause them difficulty. A114: *The professor explains relatively simple topics in a very difficult way*. The second-years report problems with the lecturer and the lack of application for the material covered as the main subfactors for why they find their Engineering Mathematics modules difficult: A212: *There was a lot of content I will never use again as an engineer.* In contrast with the first-years, the second-years report these factors as applying primarily to EM3, while the first-years report their issues applying solely to EM2. Despite referring to different modules, the sentiment expressed in the quotes was similar - the lecturer did not explain things well - A232: *I found the lecturer very hard to follow*. The third-years report that the general teaching style and the poor explanation of the material were the main subfactors which caused them to find their mathematics modules difficult. A310: *Teaching may have been better with more explanation*. This student put EM3 down as the subject they found most difficult, but we can see that EM2, EM3 and EM5 all appeared as modules that the students in third-year found at least somewhat difficult with regards to the teaching style. Through these results, we can see that there is preliminary evidence that the students in this study report factors which fall into the didactical aspect of the STT (Gueudet, 2008). Also, we can see evidence that educators in the university in which this study takes place are perhaps not employing effective pedagogical techniques, which is consistent with the literature (Knight, 2002; Murtonen and Vilppu, 2020).

We can further analyse the data by looking at the responses to Question B: *Is there anything else you found challenging about studying maths in university?,* given in Table 5. Here, all students report that the change in teaching style between secondary school and university is a major challenge that they faced while studying mathematics at university. This indicates that it is the change in structure, coupled with the lecturers' style of teaching that is contributing to the students' plight in their mathematics module. In the responses to Question B, we see responses like: B227: *Everything is self-directed learning, unlike secondary school when we were given homework every night that had to be done that night* and B301: *Generally, the change of structure from secondary school to college.* We note that universities in Ireland are often referred to as 'colleges'. It appears that the students are reporting that the change in environment is also something they have had to contend with, which is an issue commonly cited in the socio-cultural aspect of the STT (Gueudet, 2008). While this is true, we cannot be certain whether these students' quotes, who are in second- and third-year, are referring to their experiences in their current year, or to their experiences in previous years. One other insight from the responses to Question B is that the first-years report that the material is often "abstract". This echoes the so-called "abstraction shock" (Hefendehl-Hebeker, Ableitinger and Hermann, 2010), and it indicates that perhaps the first-year students in the university in this study also report issues which fall into the epistemological/cognitive aspect of the STT (Gueudet, 2008). This contrasts the second years, who report that the material is "abstract", but not as avidly as the first-years. The third-years do not report this at all, indicating that perhaps the third-years have become more accustomed to the type of mathematics students are expected to deal with at university. Moreover, students also report struggling when the lecturer does not provide all the details of a solution, which could indicate a weak understanding of the material. This shows that the

Mathematics Problem (Lawson, 2003) may also be a factor for the students here, A118: *the lecturer skipping over smaller details assuming everyone should know them but no one ever does from the people I talk to.* In the discussion so far, we have shown preliminary evidence that the students of all years in this study report facing issues that are contained within the three aspects of the STT as compiled by Gueudet (2008). However, now we will compare these findings to the students' confidence in mathematics, their perception of the difficulty of mathematics and their stress levels due to mathematics.

Firstly, from Table 2, we observe that a plurality of the first-year students responded "Neutral" to Statement 1: *During my first year I was confident with mathematics.* This contrasts with the majority of the first-years who disagreed in some way with Statement 2: *I am confident with the mathematics I am studying now*. The apparent drop in confidence is observed in the statistically significant drop in median confidence level from 3(2) to 2(1), reported by the first-years. There is evidence of a drop in confidence reported among the third-years also with the median confidence dropping from 4(2) to 2(1.5), although this was not statistically significant. Perhaps a more convincing argument of this drop in confidence is the majority (53.3%) of third-years that agreed to any degree with Statement 1 compared to the majority (53.3%) of third-years that disagreed with Statement 2. The second-years report an increase in confidence between their first-year and the time of the survey with their reported median going from 2(1) to 3(1.25), although this is not statistically significant. There is still evidence of an increase in confidence however with a majority (55.5%) disagreeing to any degree with Statement 1, but only 25% disagreeing to any degree with Statement 2.

From Table 2, we observe that the first- and third-years are relatively split on whether they found mathematics difficult in first year. 34.7% of the first years and 46.7% of the third years agreed in some way with Statement 3: *When I first started in university, I found maths difficult*, while 38.7% of the first years and 33.4% of the third years disagreed in some way. This indecisiveness is not observed regarding their perceived difficulty with mathematics now. 81.6% of the first-years and 80% of the third years disagreed in some way with Statement 4: *The maths I'm studying now is easy.* This dramatic increase in perceived difficulty of their mathematics modules between first-year and the time of the survey is reflected by the statistically significant increases in medians from 3(2) to 4(1) for both year groups. These observations are reversed with the second years with 58.3% agreeing in some way with Statement 3 and only 13.9% disagreeing in some way. This contrasts with the 50% of students who reported a neutral response, and the relatively even split between the number of students agreeing and disagreeing observed in response to Statement 4 (22.2% versus 27.8%). The reason for this is perhaps due to the modules that each year group is enrolled in at the time of completing the survey. The first- and third-years are enrolled in EM2 and EM5, both of which are represented in Table 4 as modules that the students find difficult. The decrease in confidence reported by the first- and third-years also mirror this increase in perceived difficulty although we do not have a direct causation. The second-years are currently enrolled in EM4, which was not reported by a single student as being the most difficult. Moreover, the increase in confidence reported by the second-years mirrors the decrease in perceived difficulty, although similar to the first- and third-years, there is no direct causation. Regardless of the cause, the increase in the perceived difficulty and the drop in confidence are common among students who experience symptoms of the *Mathematics Problem* (Lawson, 2003) and as elucidated by Di Martino and Gregorio (2019), even academically stronger students (such as the students in this study) are not immune from experiencing a loss in confidence when they experience an increase in perceived difficulty.

The responses to Statement 5: *When I first started studying mathematics in university, it caused me significant stress* and statement 6: *My stress levels decreased after first year*, generally continuing the current narrative painted by the previous responses. Firstly, the first-years do not seem particularly stressed with 57.1% of them disagreeing to some degree that mathematics caused them stress at the beginning of first-year. This is in contrast with 55.5% and 46.7% of the second- and third-years respectively, who agree to some degree with Statements 5 and 6. A potential explanation here could be that the first-years are comparing their experience with EM1 to that of their current module EM2, which they find significantly more difficult. They may be viewing this through rose-tinted glasses and do not recall any stress caused by EM1. The second- and third-years both report an increase in stress due to mathematics after first-year with 41.6% and 66.7% of second- and third-years disagreeing somewhat with Statement 6. These results corroborate with the results in Table 4 as EM3 and EM5 (both non-first year modules) are the most common modules listed as most difficult.

5. Conclusion

In this paper, we have shown preliminary results that three years of undergraduate engineering students in an Irish university experience issues when studying mathematics modules which are reflective of issues experienced in the STT (Gueudet, 2008). More specifically, the students reported didactical issues as a major factor affecting their perceived difficulty of mathematics in university – A129: *I feel your lecture can either make you or break you*. There is evidence that these didactical issues are not year dependent, and this is a novel result in the research on STT, where the focus has been solely on students in their first-year of university. There is evidence that the students also experience issues that can be classed under the epistemological/cognitive and socio-cultural aspects of the STT, however these are not as clear since students could be referring to previous experiences, rather than their current ones. These issues are associated with a relative drop in confidence, an increase in perceived difficulty of mathematics and an increase in stress levels among the second- and third-years. The only aberrations to these associations can be explained by looking at the modules the students are currently doing and the results in Table 4.

There are three main limitations to this study. The first was already mentioned: the sample size, particularly for the third years, is low. The second limitation is that we do not have a direct causation between the factors the students identified and their confidence, stress and perceived difficulty levels – we only have association. The third limitation is that we have not accounted for external factors such as the COVID-19 pandemic, which could have impacted the third-years (who would have completed their last year of secondary school and their first-year of university during 2020 and 2021) more than the first- and second-years. Another interesting question that is unanswered in this paper is whether the first-years in this study will report the same or similar factors as the second- and third-years did as they continue through university. To address these concerns, the authors are currently conducting a longitudinal study in which we investigate if the factors reported by the students in this study are constant or if other factors such as the COVID-19 pandemic have had a larger impact.

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[1] Only the responses from some questions were considered in the analysis carried out in this paper.
[2] “Now” refers to the time at which the survey took place. For the first years, “now” is the middle of their second semester of university, for the second years, “now” is the middle of their fourth semester of university and for third years, “now” is the middle of their sixth semester of university.
[3] In the question prior to Question A, the students were asked to rank the Engineering Mathematics modules they had completed in order of difficulty. Some modules were omitted in the first and second years’ surveys as they had not yet completed these modules.

RESEARCH ARTICLE

Investigating mathematics anxiety in out-of-field teachers enrolled in Ireland's upskilling programme

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Abstract

Research shows that many university students, including mature students, have debilitating mathematics anxiety (MA); and mathematics anxious teachers risk passing on MA to their students. This paper investigates mathematics anxiety (MA) among a cohort of out-of-field secondary teachers enrolled in Ireland's Professional Diploma in Mathematics for Teaching (PDMT). Prompted by national concerns regarding teacher qualifications, the PDMT was introduced to address a significant proportion of mathematics instruction delivered by non-specialist teachers. A mixed-methods design was used with 49 respondents completing both a qualitative survey and two measurement instruments: the Mathematics Anxiety Scale – UK (MAS-UK) and the Mathematics Anxiety Scale for Teachers (MAST). Findings indicated low-to-moderate levels of MA among participants, with anxiety predominantly associated with teaching contexts rather than everyday mathematical tasks. Qualitative analysis revealed recurring concerns related to content knowledge, instructional strategies, and confidence in real-time problem-solving. A strong positive correlation (r = .852) between MAS-UK and MAST scores highlights the connection between general and teacher mathematics anxiety. This study hypothesises that mathematics anxiety affects out-of-field mathematics teachers and considers ways to support future PDMT students in addressing and reducing mathematics anxiety. The findings underscore the importance of embedding targeted confidence-building strategies within professional development programmes to enhance mathematics teaching quality and reduce anxiety transmission to students.

Keywords: Out-of-field mathematics teachers, mathematics anxiety, professional development.

1. Introduction

Mathematics is a highly valued, foundational subject and essential to economic and educational development, underpinning advancements in science, technology, engineering and mathematics (STEM) disciplines, as well as featuring in a wide variety of academic programmes. However, research shows that persistent challenges have had an impact on the uptake of mathematics as a higher-level subject and in the pursuit of mathematics teaching as a career across jurisdictions (Goos et al. 2023; Ramirez et al., 2018; Saunders, 2025). Of significance for Ireland were the declining Programme for International Student Assessment (PISA) rankings between 2003 and 2009, where Ireland's figures dropped by 16 points, leading to a review of mathematics curricula in schools (Perkins et al., 2013). Further, the result of a national study into out-of-field mathematics teachers revealed that 48% of mathematics teachers were out-of-field, i.e. teaching mathematics without the necessary subject-specific qualifications (Ní Ríordáin & Hannigan, 2009). The findings led to the development and launch of the Professional Diploma in Mathematics for Teacher (PDMT) in 2012 as a "long-term, large scale, government-funded, university-accredited programme offered nationally" (Goos et al., 2023). A recent review of the PDMT showed that by 2020 the number of out-of-field mathematics teachers had reduced to 25% (Goos & Guerin, 2021). Initially the program required teachers to have timetabled hours in mathematics, ensuring they had some teaching experience in the subject. Many had studied mathematics in their primary degrees; now the PDMT is available to any secondary school teacher seeking qualification in mathematics, resulting in a diverse participant profile with many having no prior mathematics teaching.

Mathematics anxiety (MA) is a well-documented phenomenon that can significantly impact both learning outcomes and teaching effectiveness. Research indicates that university students, including mature learners, often struggle with high levels of MA, which can hinder their engagement and performance in mathematics-related subjects (Ryan, Fitzmaurice & Johnson, 2023). The prevalence of MA is particularly concerning in the context of pre-service and in-service teachers who lack formal mathematics education, as they may unknowingly transfer their own apprehensions to their students, perpetuating a cycle of adverse feelings towards mathematics (Brady & Boud, 2006; Dowker, Sarkar & Looi, 2016). Given that out-of-field mathematics teachers continue to be prevalent in schools, it is important to understand the extent to which MA affects their confidence and instructional quality. This study explores the extent and manifestation of MA among out-of-field mathematics teachers and proposes recommendations to help future pre-service and developing mathematics teachers build confidence, improve pedagogical strategies, and ultimately alleviate anxiety for both educators and their students.

2. Out-of-field mathematics teachers and mathematics anxiety

Out-of-field – or non-specialist – mathematics teachers are formally qualified in subjects other than mathematics but are either currently teaching or preparing to teach mathematics (Ingersoll, 2002). The issue of out-of-field teaching is significant in education, as it can impact both the effectiveness of teaching as well as student outcomes. Teachers qualified in other disciplines may face challenges in content mastery, pedagogical strategies, and confidence when transitioning to mathematics instruction (Ní Ríordáin & Hannigan, 2009). The presence of out-of-field teachers in secondary education suggests there is a shortage of, and a need for more, specialised mathematics educators.

The PDMT has significantly reduced the number of out-of-field mathematics teachers in Ireland and has facilitated a shift toward student-centred instructional approaches. The review of the PDMT programme by Goos and colleagues revealed that graduates of the programme report increased emphasis on problem-solving, conceptual understanding, and student engagement, aligning with international best practice. However, despite this progress, 25% of mathematics teachers remain underqualified; and out-of-field teachers are still disproportionately assigned to lower-level classes, and frequently first-year classes, where the quality of mathematics teaching is crucial for a successful transition from primary to secondary education (Ryan, Fitzmaurice & O'Donoghue, 2021a). If the transitional experience in mathematics is compromised by inadequate teaching, the gap between high- and low-achieving students will widen as they progress through secondary school (Ryan, Fitzmaurice & O'Donoghue, 2021b). Further, ongoing challenges in teacher recruitment and cultural attitudes toward mathematics teaching highlight the need for continued investment and systemic change (Goos et al., 2023).

In respect of the extent of MA in Ireland, there is a lack of normative data in general among students, and specifically among mathematics teachers at all levels of education (Para et al., 2024). MA is not limited to school-going students, but is also prevalent among teachers, pre-service teachers, and mature students. Research has highlighted that many educators themselves experience MA, which can influence their teaching approaches and potentially perpetuate MA among their students (Ganley et al., 2019; Ramirez et al., 2018; Ryan et al., 2023).

International assessments, such as the Programme for International Student Assessment (PISA), have documented concerning trends in MA. Results indicate that MA levels have increased since 2003, suggesting that factors such as changing educational expectations, pressures of standardised testing, and societal attitudes toward mathematics may be contributing to this trend (OECD, 2004; 2013; 2019). Understanding these patterns provides a useful backdrop to help formulate and implement strategies to mitigate MA and support students in developing a positive relationship with mathematics. In response to the growing recognition of MA as a barrier to learning, there has been an increase in initiatives aimed at raising awareness and providing support, including educational programmes, teacher professional development workshops, and intervention strategies for students and educators (Para et al., 2024). These initiatives emphasise the importance of addressing MA early, fostering a growth mindset, and promoting positive mathematical learning experiences.

Despite increasing global awareness of MA and its effects, there is a paucity of research focusing on Irish students and teachers, particularly among mathematics educators. Without such detail, it is difficult to develop tailored interventions and policies that effectively address the experiences of individuals within the Irish education system. With this backdrop, the study aims to explore the extent of MA among out-of-field mathematics teachers and proposes recommendations to support future PDMT students in reducing their own and their students' MA.

3. Research Design

We used a mixed methods approach to investigate levels of MA during the first year of the programme, a particularly important time for students as it sets the foundation for their pedagogical development and confidence in teaching mathematics (Goos et al., 2023). A paper–based, written survey was distributed to the 2024 cohort of PDMT students (n = 190) by local gatekeepers in 5 higher education institutions (HEIs) across Ireland, and participation was voluntary. All PDMT students are qualified to teach subjects other than mathematics and are doing the PDMT to gain a qualification to teach mathematics. PDMT students comprise two categories:

Category 1) those who have taught or are currently teaching mathematics and
Category 2) those who have never taught mathematics but plan to in the future.

Understanding the backgrounds and motivations of the students is crucial to designing professional development programmes to support them in delivering effective mathematics instruction. In this regard, the survey comprised two sections. Section A was a series of open-ended questions pertaining to their study and teaching of mathematics. This section was answered by Category 1) and 2) students, and included the following questions:

- How many years have you been teaching mathematics?
- What is your subject specialism (undergraduate subject(s))?
- What is your motivation for doing this programme?
- What are your fears about teaching mathematics?
- Is there a specific mathematics topic(s) do you dislike/fear?
- How do you feel about engaging with mathematics in the PDMT?

Section B comprised two questionnaires:

- The 'Mathematics Anxiety Scale - UK' (MAS-UK) with 23 statements relating to situations in everyday life associated with the use of mathematics. For each statement students select the extent of their agreement on a scale of 1 (not at all) to 5 (very much) (Hunt, Clark-Carter

& Sheffield, 2011). Scores can range between 23 (minimum) and 115 (maximum), with low scores signifying 'low MA' and high scores signifying 'high MA' (Hunt et al., 2011). This section was answered by Category 1) and 2) students.
- The 'Mathematics Anxiety Scale for Teachers' (MAST) with 15 statements relating to the teaching of mathematics. For each statement students select the extent of their agreement on a scale of 1 (not true of me at all) to 5 (very true of me) (Ganley et al., 2019). Scores can range from 15 (minimum) to 75 (maximum), and high scores can be interpreted to reflect high MA (Ganley et al, 2019). This section was answered by Category 1) students only.

4. Analysis and Findings

The response rate was 26% (49/190). Qualitative data were managed through NVIVO and analysed using thematic analysis, while quantitative data were entered into and analysed using SPSS. Responses to Section A reveal that a majority of respondents (84%) are either currently teaching or have taught mathematics, indicating proactive engagement with mathematics instruction methods, despite lacking formal qualifications in mathematics. Of these respondents, 45% have been teaching mathematics for just one year, 21% for two years, and 18% teaching it for three or more years. The data highlights a disparity between teachers' undergraduate specialisms and the subjects they teach, particularly in mathematics where 61.2% of these PDMT candidates are assigned to teach it, despite it not being their dominant undergraduate specialism; in contrast, the percentages of this cohort teaching subjects like business (30.6%) and science (30.6%) show closer alignment with their undergraduate specialism (36.7% and 30.6% respectively).

The key motivations for doing the programme include a love of mathematics/problem-solving/working with numbers/logical reasoning (43% of respondents); job security/permanent position/career prospects (22%); the joy of teaching mathematics/helping students overcome struggles (18%); and other factors included professional development, logical appeal, and student support.

Respondents expressed a variety of fears about teaching mathematics (Table 1).

Fears about teaching mathematics – categorisation of responses and sample themes	
Categories	*Themes*
Teaching process and methodology (25%)	Fear of making mistakes while teaching Struggles with working out answers in real-time Worry about explaining concepts correctly Fear of lacking effective teaching skills
Understanding the content (20%)	Difficulty understanding the entire curriculum Feeling out of depth in some topics Lacking confidence performing mathematical calculations
Depth of knowledge and theory (20%)	Worry about not having thorough knowledge Inability to explain reasoning behind topics or calculations Confusing or mixing up formulas Lack of confidence covering Leaving Certificate HL content
Self-identity and confidence (20%)	Feeling not good enough or that their standard is too low Unsure how to support students effectively Lack of confidence in specific topics or calculations
Concerns about students (15%)	Fear that students might fail because of them Concern that students may develop a bad attitude to mathematics

Table 1 – Respondents' fears about teaching mathematics by category

These categorisations provide an insight into the fears associated with teaching mathematics among the cohort, with a particular recurrence of themes relating to a lack of mathematical knowledge, making mistakes in front of the students, and getting stuck or being unable to explain something.

The responses for least liked mathematics topics reveal that probability (39.1%) is the most disliked, followed by statistics (26.1%), algebra (13.0%) and geometry (13.0%). Trigonometry, vectors, indices, and calculus each yielded 8.7%, with 4.3% dislike of arithmetic, surds, and financial mathematics.

Their responses in relation to engagement with mathematics in the PDMT programme show that many enjoy the challenge, sense of achievement, and support structure through tutorials. While the course is perceived as manageable with effort, some find it 'daunting,' 'fast paced,' and 'more difficult than expected,' leading to feelings of being overwhelmed. Time constraints and limited opportunities for interaction in recorded sessions are also noted challenges.

For section B responses, Figure 1 shows the distribution of MAS-UK scores for a sample of 46 respondents with observed scores ranging from 23 to 79, indicating low to moderate levels of mathematics anxiety.

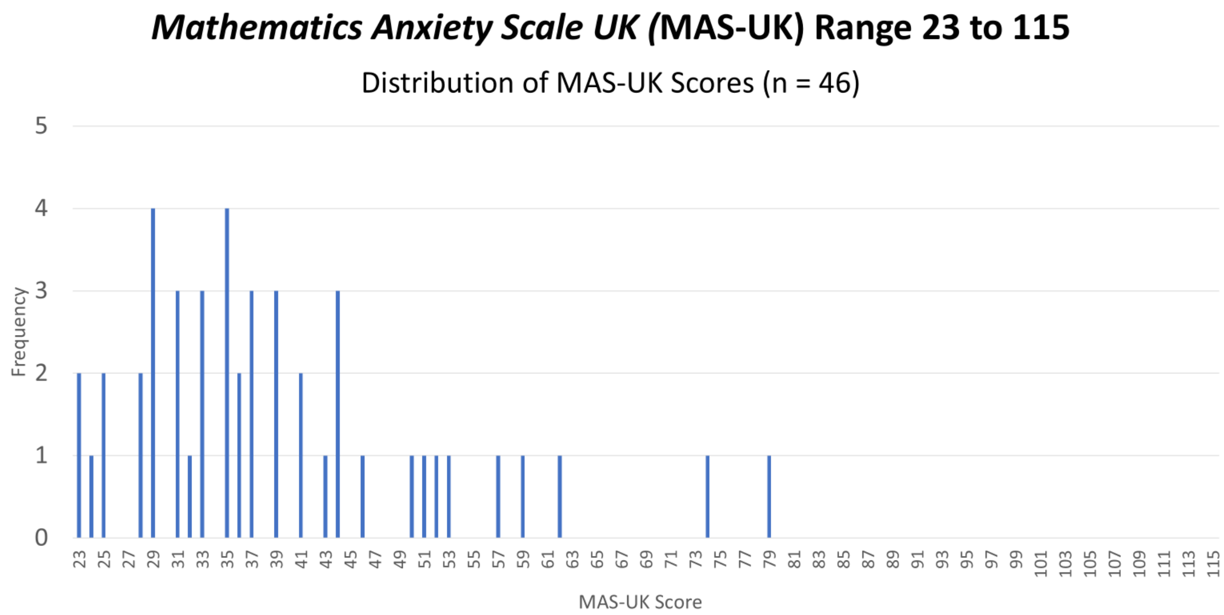

Figure 1 – Mathematics Anxiety Scale UK (MAS-UK) Scores

Most respondents scored between 30 and 40 indicating low to moderate levels of math anxiety, with a few cases above 65 and none beyond 80. This suggests that severe math anxiety is either rare or absent in this sample.

The MAST distribution (Figure 2) shows scores ranging from 15 to 73, with most clustering between scores of 25 and 40 indicating mild-to-moderate mathematics teacher anxiety.

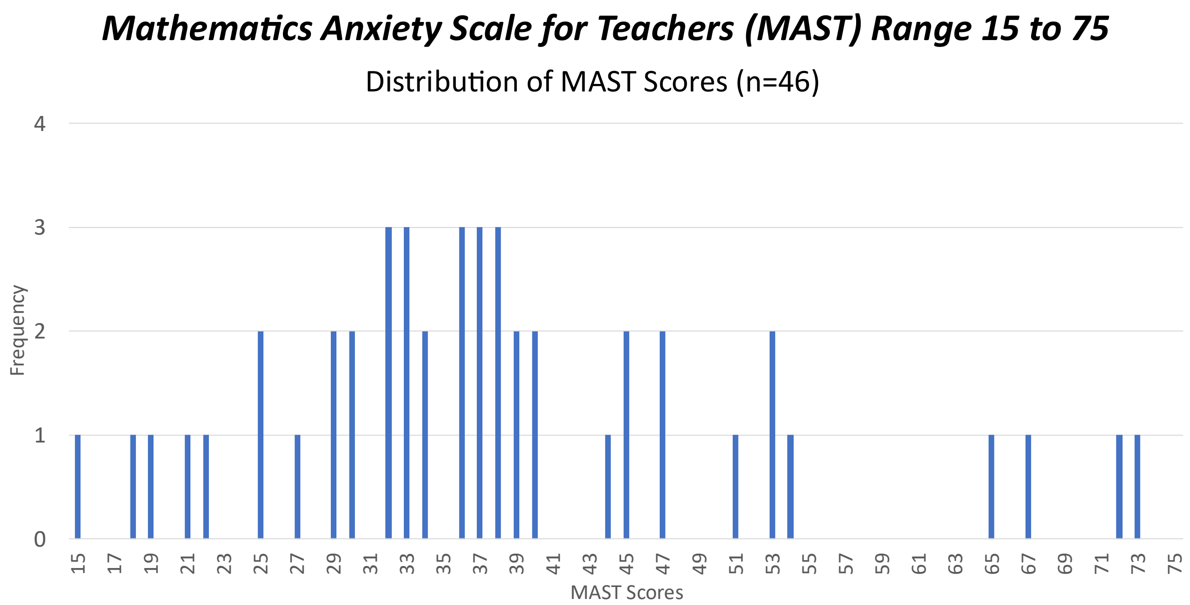

Figure 2 – Mathematics Anxiety Scale for Teachers (MAST) Scores

Peak frequencies occur at scores of 32, 33, 36, 37, and 38, while higher anxiety scores are less common suggesting that severe MA is rare in this cohort.

A strong correlation was identified between the MAS-UK and MAST scores (r = 0.852); this finding suggests that individuals exhibiting elevated levels of MA on the MAS-UK also tend to report similarly high levels of anxiety on the MAST. MAS-UK results for this cohort of teachers show low-to-moderate anxiety levels in evaluative situations, like testing or writing on the board, while everyday mathematics activities cause minimal anxiety. In contrast MAST scores follow a more normal distribution with teachers experiencing moderate anxiety levels particularly related to teaching and social evaluative situations. This finding demonstrates that, in contrast to the MAS-UK, the MAST reflects a broader distribution of mathematics anxiety among this cohort of practicing teachers.

5. Discussion and Conclusion

Mathematics plays a critical role in fostering STEM careers, yet in Ireland progress has been impeded by persistent challenges such as the low uptake of higher-level mathematics and a significant number of out-of-field mathematics teachers. This study set out to investigate mathematics anxiety among a cohort of out-of-field teachers enrolled in the PDMT programme across Ireland. However, despite the low response rate, the findings offer valuable quantitative and qualitative insights into this under-researched population.

Analysis of the findings revealed that, in general, MA is low among this cohort, suggesting that professional development should prioritise building mathematical confidence among teachers rather than broad anxiety reduction. The findings highlight that the majority of respondents are or have been engaged in teaching mathematics, despite lacking formal qualifications in the subject. Motivations for enrolling in the PDMT programme include a passion for mathematics and problem-solving, the desire for career stability, and the fulfilment derived from helping students succeed in mathematics. However, respondents also reiterated their fears about teaching the subject, with key concerns relating to instructional methodology, content mastery, depth of understanding, self-confidence, and student-related worries. A recurrent theme was anxiety about making mistakes, struggling with real-time problem-solving, and insufficient mathematical confidence. Many admitted having experienced challenges with probability, statistics, algebra and geometry, suggesting a need for greater instructional support, better concept reinforcement, and the use of real-world applications to enhance engagement across mathematics topics. Despite the challenges identified, respondents reported enjoying the intellectual challenge and support provided through the PDMT.

Findings from both the MAS-UK and MAST scales suggest that MA is more pronounced in evaluative and instructional contexts compared to everyday mathematics usage, aligning with research findings on MA among teachers (Ramirez et al., 2018). While most respondents experience only mild to moderate levels of MA, the additional pressure of teaching mathematics effectively exacerbates these feelings. The strong correlation observed between the MAS-UK and MAST results reinforces the idea that anxiety patterns among teachers closely mirror those found in the general population, but with added stressors related to teaching and public performance. Addressing these anxieties through confidence building strategies, professional development, and supportive teaching environments aligns with Bandura's (1997) emphasis on mastery experiences as foundational to developing self-efficacy, and suggesting that targeted professional development interventions could mitigate mathematics teacher anxiety.

These insights into the experiences of PDMT students are significant in that they highlight the challenges they face with mathematics, their coping mechanisms, and the support they need as out-of-field mathematics teachers. Although limited by the scale of the study, the findings align with existing research (Dowker et al., 2016; Ganley et al., 2019; Ramirez et al., 2018) and underscore the importance of integrating explicit mathematics anxiety reduction strategies into national professional development programmes, such as the PDMT, as well as in policy frameworks guiding mathematics teachers qualification. In this regard, the study offers insights for addressing teacher MA in the Irish context and emphasises the importance of professional development upskilling within education policy.

The findings show that these out-of-field teachers face challenges that can be addressed by engaging with professional development and pedagogical support to enhance their mathematical confidence and instructional effectiveness. Initial teacher education programmes and in-service professional development programmes for high stakes subjects like mathematics, need to reiterate the importance of improving subject mastery, developing and implementing strategies to reduce MA and cultivate mathematical resilience, and enhancing the overall quality of mathematics teaching.

On completion of the PDMT, the researchers intend to invite this cohort of students to complete section B of the survey again in order to conduct a pre and post comparison of students' MA levels.

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RESEARCH ARTICLE

Barriers to mathematics learning and engagement created by academic stereotypes and experiences

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Abstract

In a Higher Education context, most research into stereotypes focuses on the negative impact of stereotypes that educators hold about students. However, this study focuses on whether students also hold stereotypes about academic staff, and whether this also results in negative consequences for students. Focus groups with students in both mathematics and humanities departments identify four potential barriers to student learning and engagement created by the stereotype that staff are intellectual, powerful, research-focused and middle-aged white males. Implications for students and steps that staff can take to address these barriers are discussed.

Keywords: Academic stereotypes, student engagement, student belonging.

1. Introduction

Following Fricker (2007), 'stereotype' refers to widely held associations between a social group and specific attributes, and such associations are considered indicative of a stereotype even if the term itself is not explicitly used. Stereotype threat is characterised as where an individual feels at risk of conforming to a negative stereotype held about them, and this fear leads them to underperform and perpetuate the stereotype (Steele and Aronson, 1995). In an education context, stereotype threat is almost exclusively framed in terms of the negative consequences for the learner based on their fear of stereotypes held about them by their educator. For example, it has been demonstrated in connection to ethnicity (Osborne, 2001), gender (Spencer et al., 1999) and socio-economic status (Croizet and Claire, 2021). However, this study considers what stereotypes undergraduate students hold about university staff and whether these also create barriers to student learning.

The project was borne out of an open call for academics to come together to discuss whether they had experienced stereotype threat. Approximately 12 staff members, including the authors, took part in an initial discussion, with the authors then choosing to meet regularly and form a research team for the current project. Further discussions within the team provided a starting point for research considering the issue of academic stereotypes, but the team needed to begin with their own experiences before researching and understanding those of others. The research team comprised two female and two male academics who had not previously worked together on a project, all of whom are White British and educated to doctorate level. It emerged that they were conscious of stereotypes held about them by colleagues based on background: "*I am conscious of, and at times have felt inferior to, many senior colleagues who attended grammar or private schools and are Oxbridge [Oxford or Cambridge] educated"*; being teaching-focussed: "*When introduced as 'Professor', I get embarrassed, unsure if I've truly earned that title. I worry people will expect many* *books and I have to awkwardly explain I'm not that kind of professor"*; or being female: "*As a female colleague I have experienced male academic behaviour towards me that has been demeaning and, sometimes, simply rude."* It was evident academic stereotypes had influenced, shaped and, at times, obstructed the team members' professional identities and ability to do their work. As the research drew on their prior experiences, the process of reflecting, sharing, analysing and writing required them to live, tell, re-tell and re-live their professional life stories.

However, the discussions led the research team to reflect on whether students also hold stereotypes about staff and if the notion of stereotype threat could be turned on its head, and that there may be negative consequences for the holder of the stereotype. Academic stereotypes are derived from norms, and, in a selective university, those norms still enable some while obstructing others. Identity, gender, role focus and nomenclature have influenced each author's self-perception and understanding of their place in the academic hierarchies. As one team member observed: "*This all speaks to fundamental issues about the role and identity of a university and its members, including what titles signify and what work 'counts'. These complex social norms are what make projects like this so pertinent."*

Research shows that the use of language in Higher Education, such as 'Teacher', 'Lecturer', 'Dr' and 'Professor', significantly influences the student-teacher relationship (e.g. Ellis and Travis, 2007). Research suggests that these titles can shape both the identity of educators and impact their interactions with students (Baxter, 2012; Hockings et al., 2009). The complexity of the Higher Education environment, including increased external accountability, pressure to teach employability skills as well as subject knowledge, diverse student needs and research targets, further complicates these interactions (Lea and Callaghan, 2008; Hockings et al., 2009). Therefore, the language used in universities can have a profound effect on how the Higher Education community sees and interacts with one another. Further research has shown how stereotype threat and silencing can alter and affect the Higher Education experience for both students and academics (Fisher, 2010; Fisher, 2021).

This study builds on many of these insights and asks how certain terms are heard and responded to in a large Russell Group university in the UK. The research questions what stereotypes students hold about staff and what impact this has on student learning and engagement for mathematics and humanities students.

2. Methodology

This research into academic stereotypes took a layered approach to investigating the issue. Firstly, focus groups with nine humanities students set out to establish what academic stereotypes exist. Students were presented with various academic terms, e.g. 'professor', and asked for the associations, experiences and feelings the words created. Although all the students studied humanities subjects (e.g. philosophy), no context or subject disciplines were attached to the words presented. Subsequently, a second set of focus groups with seven mathematics students explored the impact stereotypes had on staff-student interactions. The mathematics students were asked to describe the roles and types of academic staff. Inevitably, the conversations for both humanities and mathematics students meandered and covered both perceptions of academics and lived experiences.

Once the data had been collected, a thematic analysis of each of the humanities and mathematics data was undertaken by two team members to enable a range of perspectives on the initial coding or thematic analysis. Further discussions then interrogated the themes and commonalities which had arisen from each researcher's analysis.

The data was sufficiently rich that the emerging themes could be organised in multiple ways, each giving subtly different emphases to the findings. For example, the research could have focussed purely on the language and labels students use to describe staff. However, in this paper the focus is on the impact of academic stereotypes on students in terms of their barriers to engagement and learning. Each researcher then added what they perceived to be relevant data under headings that had been collectively agreed.

3. Barriers to students

Collective discussion of the data identified key themes around academic stereotypes. The humanities data establishes student perceptions and the assumptions they hold about staff based on the language used. The mathematics data explores how stereotypes, whether perceived or experienced, play out in an academic school and the real, potential or perceived barriers these create for student engagement and learning. These themes are discussed below with quotes from students which exemplify the views expressed.

3.1. Intellectual barrier

One stereotype prevalent in the comments from both humanities and mathematics students alluded to academic staff being on a different intellectual level to students. This may partly be due to language because the word ‘academic’, for example, can be: “*daunting and create an immediate divide”* (humanities student). Several mathematics students said this intellectual divide was intimidating, such as: “*I almost felt intimidated slightly because they are so incredibly intelligent”* (mathematics student).

This assumption that staff are on a different intellectual level means students become anxious about interactions with staff. When students think about ‘engagement’ with staff it stirs unhelpful feelings: “*I personally feel imposter syndrome sometimes, and myself and my classmates talk about how we don't feel comfortable contributing unless we have something really good to say. I guess there's like an invisible pressure that we put on ourselves so I feel nervous about contributing*.” (humanities student) and negatively impacts interactions: “*it can be difficult to sort of engage them sometimes just because there is such a [intellectual] gap”* (mathematics student), especially in whole-class discussions: “*if you’re sometimes asked a question, you'll think a bit like ‘Oh God, he thinks I'm really stupid’”* (mathematics student).

The student comments suggest overcoming the barrier can be achieved by staff adopting a more responsive attitude: “*the lecturers I get along with most are definitely ones that seem to have a never-ending capacity for unusual questions”* (mathematics student).

In mathematics, presenting material at an appropriate level and pace for students to engage with requires careful thought: “*their brains work much quicker than ours and it clicks for them, not necessarily for us”* (mathematics student) and inclination: “*I've had a lecturer that's very senior taking a first-year module, and clearly they are like much smarter than all these first years, and obviously they have much more interesting things to be doing than teaching first-years rudimentary maths”* (mathematics student).

3.2. Status barrier

Student comments suggest a stereotype of academic staff being placed, or placing themselves, on a pedestal. This is partly due to the job titles and hierarchies within Higher Education: “*You have ‘associate professors’ and then ‘professors’ and ‘assistant professors’. It’s very strange. And you're like, ‘What are the differences?’”* (mathematics student). It also relates to the power staff hold over student learning: "*I've had both positive and negative experiences that helped me understand how much power they [professors] hold in making a module interesting for me. This ultimately determines the quality of work I produce for it too*" (humanities student).

This unbalanced power dynamic between staff and students can manifest itself in the way staff teach. For example, 'lecturer' is associated with: "*the impression that they are not approachable and speak at you rather than with you. I think the term 'lecture' in itself feels passive and aggressive rather than promoting a positive and inclusive learning experience*" (humanities student). Further, it gives staff unnecessary control of the view expressed: "*I felt from them [professors] they tend to restrict student's opinions in terms of studying ...... they tend to teach only liberal side and never mention about right wing side or mention it in a negative way that I often felt so limited and frustrated*" (humanities student).

The stereotype is therefore that students perceive academics to feel self-important, reinforcing any student imposter syndrome. This stereotype strongly contrasts with student perceptions of school teachers who are much more positively viewed: "*Teachers are like extremely approachable*" (mathematics student) and "*Someone who enriches the life of many young people*" (humanities student). While students enjoy a "*much more back and forth, reciprocal relationship*" (humanities student) with teachers in schools, at university students see power symbols like hierarchical job titles, staff being both educators and examiners, and the teacher-led styles of teaching. The stereotype could form a barrier to engagement, particularly for those first-in-family students unfamiliar with university terminology and teaching styles.

3.3. Identity barrier

Students have strong positive associations with the word 'community': "*We are part of the [university] community. It definitely gives a sense of home and belonging which is really important*" (humanities student). However, that sense of community and belonging is closely associated with identity and being with people they identify with: "*Due to the dense Indian population in our university, I've been fortunate to find a sense of community*" (humanities student). Minority ethnic students reported it is sometimes challenging to break barriers and socialise in a predominantly White community due to cultural differences, so they seek community outside the classroom: "*I am an Asian female so I seek finding a sense of community and belonging within societies*" (humanities student).

Within the classroom, students may not identify with the teaching staff. One student noted that sometimes her racial identity was questioned or assumed, whereas others noted the gender imbalance is particularly notable: "*I can only think of one female lecturer*" (mathematics student). While the staff gender balance may vary between subjects, the word 'professor' was associated with: "*usually old male lecturers who are very senior*" (humanities student), and it was noted: "*men are overrepresented in positions of seniority in the maths department generally*" (mathematics student). This perception may contribute to gender gaps in students where, for example, female students only make up around a third of the mathematics cohort nationally. A more subtle identity issue arises around personality types. The introverted nature of some mathematics academics meant they were: "*quite quiet sometimes and you have to kind of make the effort to go [to them] if you want help*" (mathematics student).

The academic system has therefore created a stereotype of White males, perhaps those with the time for solitary focus on research outputs, and the classic "*old Einstein looking man with blackboard*" (humanities student) image of a professor creates both a barrier to inclusion for current students and a barrier to more equitable recruitment in the following generation. However, this identity barrier may not be one that all students experience depending on the socio-cultural capital they bring to the classroom.

3.4. Priority barrier

Unlike in the school system, where students and teachers are both (rightly or wrongly) measured by student grades, in the university system students and staff have different priorities. Students reported that some staff would: "*much rather be doing research*" (mathematics student) and this can result in poor teaching: "*they turn up and they read their thing off the slides and then they go back to their research*" (mathematics student) and poor pastoral care: "*I'm still not sure what a personal tutor does*" (humanities student).

For some students, being taught by researchers is important: "*I always feel an immense amount of respect for a professor because of how much hard work that must have taken. Generally, I feel like they're pretty good at expressing ideas and theories*" (humanities student). However, for other students, receiving good teaching is paramount: "*I am of the stance that because you're good at research doesn't make you good at teaching. We now value those as two separate skills and you can be good at one not the other, or good at both, or good at neither*" (mathematics student).

The dual priorities of academic staff lead to inconsistent teaching quality, with some staff being: *"very forthcoming and like helping us through it*" (mathematics student) while at other times "*I go to a problem class and I'll kind of feel like the professor wishes they weren't there*" (mathematics student) and inconsistent pastoral care: "*I immediately think of the varied experiences myself and my peers have had - some [personal tutors] are great, caring, communicative etc. Others, the opposite of this. I have been so lucky to have a brilliant personal tutor but am aware that this is likely because they are well established in the department and the faculty, so they are incredibly aware of procedures, services etc. because of previous positions they held. I wish it was the same for everyone, but sadly this is unrealistic*" (humanities student).

There is a danger that the competing research and teaching priorities on staff time perpetuate stereotypes previously mentioned and create a barrier for students, increasing experiences like: "*some of the [pastoral] meetings feel like a formality, a box to be checked*" (humanities student), while only more conscientious members of staff shoulder the burden of supporting students: *"how to make the support available more uniform across the board is a whole other question*" (humanities student).

4. Implications

The student data identified four connected stereotypes of academic staff, each of which creates a barrier to student learning and engagement (see Figure 1). But why do these stereotypes exist?

Firstly, they are self-perpetuating. Students who 'fit in' whether on economic, ethnic, cultural or personality grounds are more likely to be academically successful, finish their degree and become academics themselves (Beasley and Fischer, 2012). This is the stereotype threat, as applied to students, that is well-documented in the literature. Similarly, newer university staff members may experience stereotype threat compared to more 'successful' colleagues with regards to retention and promotion, as is experienced in other workplaces (Walton et al., 2015). Indeed, this project started with staff members meeting to discuss their experiences of stereotype threat. Consequently, stereotypes in the upper echelons of academia are reinforced.

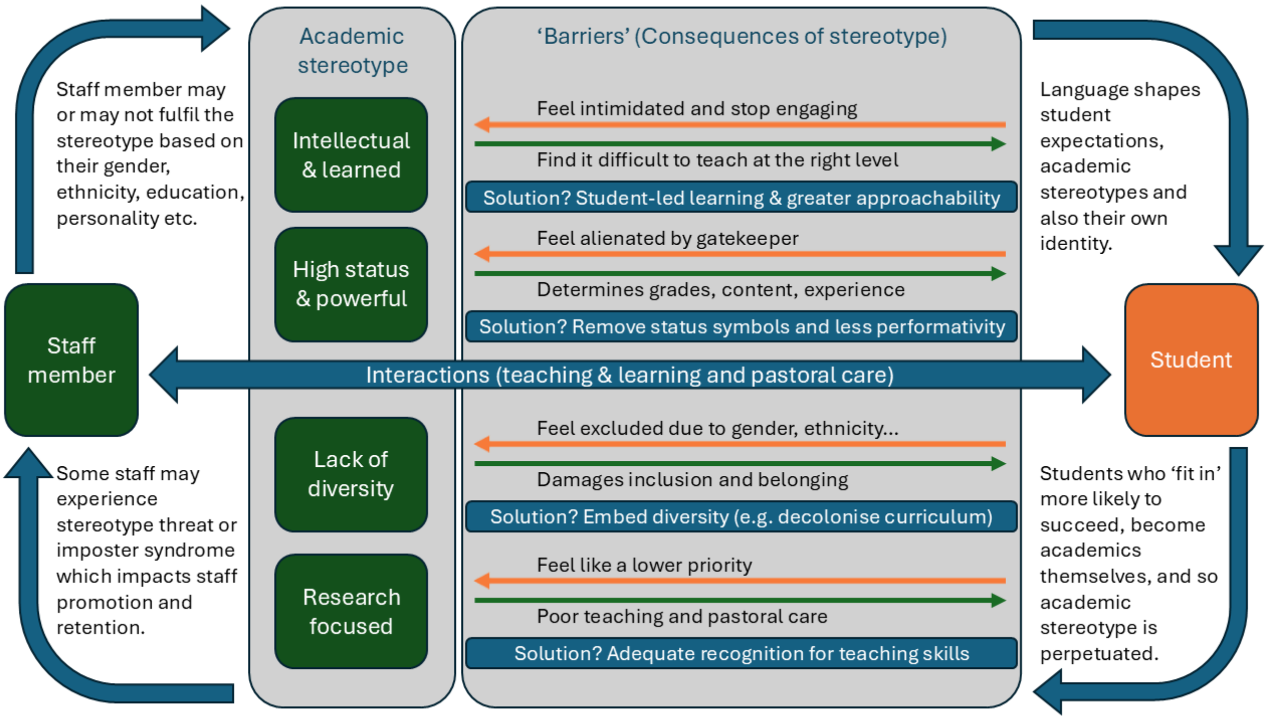

Figure 1. Schematic diagram showing the academic stereotypes, and their barriers to students, as discussed in this paper.

Secondly, there is the language used. Even before setting foot in a university, a student will have pre-conceived ideas from media and marketing material of what it means to be 'lectured' by an 'academic'. Terms that conjure status hierarchies can cause differential treatment of students by ethnicity, gender, or other identity markers (Oldmeadow and Fiske, 2010; Amoroso et al., 2010). Beyond its capacity to 'other' (Phiri, 2014; Sarukkai, 1997), unreflexive terminology also arguably stunts the pedagogical creativity and sense of vocation that initially draws many to academia.

Although prompted in slightly different ways, and despite studying very different disciplines, there is considerable overlap in the themes that emerged from both the humanities and mathematics students. Without being given the context of specific staff or modules, their similar general descriptions of academic staff stereotypes sometimes strayed into describing specific lived experiences. Sometimes these experiences are the consequence of stereotypes and sometimes they help reinforce existing stereotypes. Regardless of how stereotypes are created or whether these stereotypes are imagined or real, it is inevitable that students will approach their next interaction with staff with pre-conceived ideas of the staff member's appearance, role and priorities. Therefore, it is helpful to consider how student perceptions may be addressed and the barriers broken down.

Firstly, students hold a stereotype that staff are intellectual and learned to the point of being intimidating. This could be addressed by staff adopting more student-led forms of learning and adaptive teaching, which are responsive to student queries, compared to the more traditional staff-led didactic approaches where academics project an all-knowing persona that leaves students anxious about engaging them. For example, one of the authors now uses flipped learning, which has been shown to boost engagement and, hence, satisfaction (Fisher et al., 2018).

Secondly, staff stereotypically have high status and use their power to influence curriculum, grades and the student experience. Potential solutions involve removing job titles which, according to the student focus groups and other research (Morling and Lee, 2020), are meaningless to many students. Additionally, one author now deliberately refers to their family and outside interests when introducing themselves to students to make them more approachable. Staff can also seek to replicate teacher-pupil dynamics seen in schools. For example, one author has used co-creation (Bovill et al., 2016) to give students greater agency in their education and reduce the influence of the staff member.

Thirdly, there is the physical stereotype of an academic based on their age, ethnicity and gender. Multiple initiatives to support equality, diversity and inclusion such as peer mentoring, Athena Swan and widening participation aim to support students not in the majority. It should also be recognised that some staff may experience similar barriers when interacting with senior colleagues. Women, for example, are underrepresented in senior leadership within universities (Grummell et al., 2009) and particularly in mathematics. Within the classroom, solutions may be found in creating a safe environment in which students feel comfortable to express themselves, such as through decolonising the curriculum (Winter et al., 2022).

Lastly, there is the stereotype of function – that staff have to juggle the priorities of research and teaching. Giving greater recognition and importance to teaching for all staff may encourage greater pedagogical creativity and rekindle the sense of vocation that draws many to academia. However, historically, research skills are more highly valued by institutions (Parker, 2008). One department in this study has nearly 30 research professors but no staff focussed on teaching or student experience of the same rank, suggesting the two skills remain unequally valued. The mathematics department has seen substantial growth in the number of teaching-only staff at lower ranks. This replicates a pattern seen at many Russell Group universities, but there is concern this growth has not been strategically planned and is simply to release other staff for research (Wolf and Jenkins, 2020). The data collected in this research strengthens the authors' call for teaching skills to be more highly valued.

In summary, this study has investigated stereotypes held by students about academic staff, and some of the barriers to learning and engagement these stereotypes can create for mathematics and humanities students. It is acknowledged that these barriers to learning will be experienced to different extents by each individual student and may be more prevalent in some departments and institutions than others. Students in the focus groups also voiced positive comments about staff and their teaching but this paper has focused on comments relating to stereotypes, which are typically negative. Experience suggests that stereotypes and their impact will not disappear quickly or with a single initiative, but this paper proposes steps that individuals, departments and institutions can take to create environments in which more students will feel supported and a sense of belonging.

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RESEARCH ARTICLE

Trends in Attendance and Queries in a Single Maths Support Helproom

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Abstract

The 'Hub' at the School of Mathematics and Statistics at the University of Glasgow is a support help room for level 1 and 2 students, staffed by PGT students, PGRs, and course lecturers. Due to large cohort sizes, Glasgow has moved to a 'team teaching' model for lower-level courses in which each course has at least two lecturers. Given this, all office hours for level 1 and 2 classes take place within the Hub. Given the size of the pre-honours cohort and the large number of staff members of whom they can ask questions, it is difficult for any one staff member to glean an accurate picture of the areas in which students are struggling. In the current academic year, we asked Hub staffers to record the student number, course code, and question topic for each query asked of them in the Hub. Attendance data were recorded on a printed register by the staffer and later digitised by the investigator. These data were manually aggregated into a database and obvious errors corrected manually. From the details of approximately 1000 student queries, we seek trends on the impact of engagement on final grade, and to identify gaps in students' knowledge.

Keywords: mathematics, statistics, support, help room, MSC.

1. Introduction

Mathematics support centres (MSCs) are spaces in which students can seek mathematics- and statistics-specific learning support to aid in their transition into higher education (Matthews et al., 2013). The number of MSCs has been growing over the past 20 years with increasing institutional support (Kyle, 2010; Croft et al., 2015). An appraisal of the effectiveness of mathematics support centres can be found in Gillard et al. (2011). At the University of Glasgow there are two such services – one for students enrolled in level 1 and 2 courses taught by the School of Mathematics and Statistics, and a more centralised MSC for students in search of support in any course that involves mathematics or statistics. The former is colloquially known as the Maths & Stats Hub, or simply 'the Hub', and has been running in its current format since 2019. The latter is used by students across the university pursuing courses such as Engineering, Economics, Life Sciences, etc., and is organised centrally by the University via the Student Learning Development (SLD) service.

The Hub is housed in one of two teaching rooms in a centrally located building on the main university campus and is staffed for two hours per day, every day of the week during both semesters. There is a dedicated Hub page on the virtual learning environment (Moodle) used at the university. Level 1 and 2 students are automatically enrolled to this page if they are enrolled in any level 1 or 2 mathematics or statistics course. Here, enrolled students can find a timetable that details which staffers are due to attend each session, the courses in which the scheduled staffers are scheduled to offer help, and the location where the Hub will take place. Hub staffers are academic staff with lecturing responsibilities, post-graduate research students (PGRs), final year undergraduate students, or taught master's students.

Due to large cohort size, rooming constraints, and timetabling constraints, most level 1 and 2 courses make use of team-teaching wherein two lecturers deliver the same material to different lecture streams usually on the same day, but always at different times. Both lecturers of each course are asked to hold one office hour per week. These office hours appear on the Hub timetable and take place in the Hub during its normal hours of operation. Additional sessions are scheduled prior to the winter, spring, and summer examinations.

2. Materials and Methods

The rooms in which the Hub is located contain several tables, around 25 chairs, and a plethora of writing surfaces. Typically, a staffer assigned to a given course will sit at a table unoccupied by another staffer (if possible) or at the same table as another staffer if they are assigned to the same course. Attendance at the Hub is strictly optional but recommended and promoted heavily by teaching staff. When a student presents at the Hub, they are typically greeted by a staffer who asks for which course they are seeking help and directs them to the staffer assigned to that course. That staffer will then either help the student if they are available or they will be asked to wait until other students' queries are addressed.

Attendance is not taken in level 1 or 2 lectures, tutorials, or labs. All level 1 and 2 courses contain some element of continuous assessment, and this accounts for around 20% of the final grade of a student, although this may vary between courses. Typically, this is in the form of written homework with either multiple choice questions, long answer questions, or a combination of the two. All student work is marked digitally (some automatically) by large teams of tutors to limit workload for any one staff member.

Given that office hours all occur in the Hub, all Hub sessions for a particular course can be thought of as an office hour. Further, given the number of people involved in the marking processes, it is unfeasible for a course head to gauge interest in their course of the cohort as a whole and they cannot know the topics about which students ask during Hub sessions without asking each tutor.

3. Data Collection

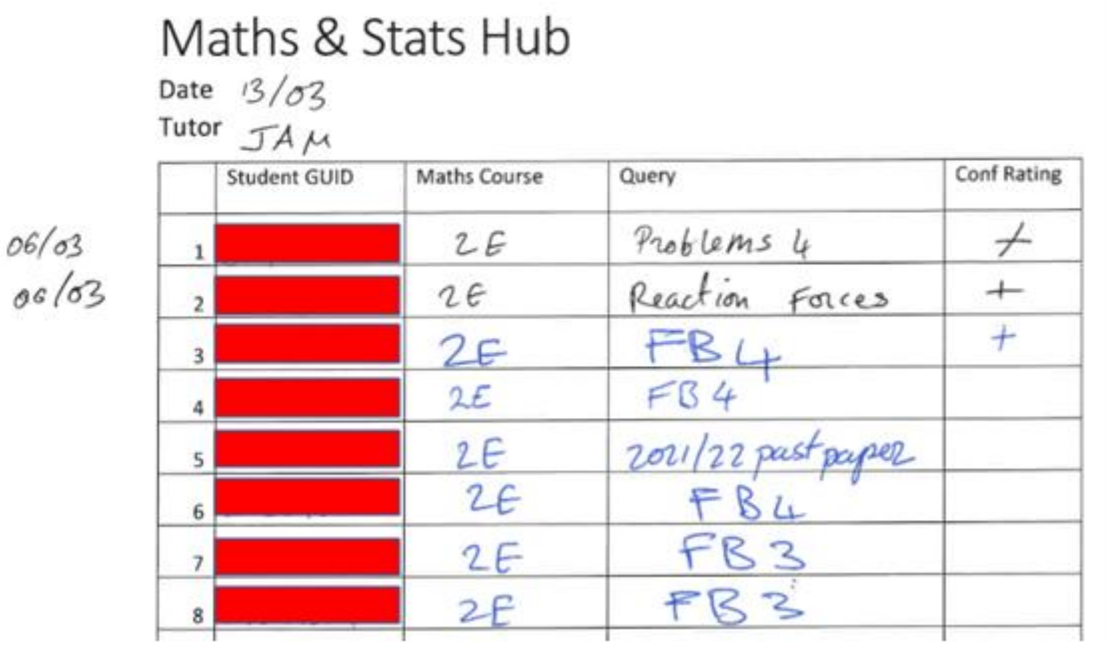
As no attendance is taken at lectures during the semester, there is no good proxy for engagement with a given course. During the academic year 2023/24 we asked Hub staffers to collect details of the students attending their Hub session as a proxy metric for attendance. The details that we asked staffers to collect were the:

- staffer's name;
- date on which the session occurred;
- students' matriculation number (GUID);
- the course about which they were asked;
- a brief summary of the question (limited to a few words);
- and a 'confidence rating'.

An example of a completed, but redacted, attendance sheet can be found in Figure 1.

Ethical approval for this data collection effort was sought from and approved by the College of Science and Engineering Ethics Committee (University of Glasgow), as it does not interfere with the learning process and essentially amounts to taking attendance in an optional class.

Staffer name and the date on which the session occurred were used to track the sessions for which data had been successfully collected. Staffer performance was not evaluated. The date on which the data were recorded were used to analyse temporal attendance trends. The student number was used to collect the queries of a given student across time. The course about which a question was asked helped to make sense of the query that was asked and aided in analysing engagement with each course. A summary of the question that was asked was intended to help identify post-COVID knowledge gaps and to identify potential issues with teaching materials.



Maths & Stats Hub

Date 13/03

Tutor JAM

		Student GUID	Maths Course	Query	Conf Rating
06/03	1	[redacted]	2E	Problems 4	+
06/03	2	[redacted]	2E	Reaction Forces	+
	3	[redacted]	2E	FB4	+
	4	[redacted]	2E	FB4	
	5	[redacted]	2E	2021/22 past paper	
	6	[redacted]	2E	FB4	
	7	[redacted]	2E	FB3	
	8	[redacted]	2E	FB3	

Figure 1: An attendance sheet completed by J.A.Mackenzie on 06 and 13 March 2024 during an office hour for Maths 2E. The red boxes are added for publication and serve to redact the students' GUID.

The 'confidence rating' was filled in by the staffer out of the sight of the student after the interaction had ended. Initially no guidance was given on how to fill this in – some staffers assigned a rating out of 5 or 10 and some used Boolean differentiators. Given the variation in rating systems, we map confidence ratings onto a 3-point scale: negative, neutral, and positive. Ratings out of 10 are mapped onto this scale based on thirds — scores of 0 to 3 out of 10 are deemed negative; scores of between 4 and 6 are neutral; and scores of 7 – 10 are deemed to be positive. In the above table the missing confidence ratings are taken to be neutral. The example does not show a negative score, but such a rating would be indicated by a minus sign. Generally, a low or negative score indicates that the student is more confused or has more questions after an interaction than they did before. A '0 score' indicated that the student is equally confused, or their question was not resolved during the interaction. A positive score indicated that the student has a better understanding of the topic post-interaction. Confidence ratings were not used to evaluate staffer performance. Robustness of confidence rating as a metric could be improved in the future by giving staffers clear guidance on the scale that should be used and by differentiating between the lack of a confidence rating and the assignment of a neutral rating.

4. Data Collation

During the semesters, staffers were periodically asked to return their sign-in sheets digitally or physically to the authors. Approximately 250 completed sheets were returned dated between October 2023 and August 2024. These had been completed by 49 unique staffers and detailed 1365 student queries. There are queries pertaining to 17 separate courses – 3 of these are level 1 mathematics courses, 2 are level 1 statistics courses, 8 are level 2 mathematics courses, and 4 are level 2 statistics courses. Initially, sheets that were returned physically were hand-sorted into two-sided and one-sided stacks and scanned. This created a PDF copy of all the sheets in a given scanning batch. All sheets were then available digitally. A webservice (https://extracttable.com/) was used to extract the hand-written information in the sheets to an Excel-compatible format. Each A4 side was extracted into its own spreadsheet; these did not contain the name of the staffer who collected the data, nor the date on which they were collected.

In order to simplify the process for themselves, many staffers used the same sheet(s) for multiple weeks, indicating in a prepended column the date on which each entry or set of entries was recorded. Given this, it was easier to manually parse the sheets for the date of each entry rather than to attempt to automate the task. The individual spreadsheets from extract tables were amended to include the date on which each query was made, along with staffer name. These individual spreadsheets were then aggregated into a database of all queries. Optical character recognition has become an increasingly powerful tool in recent years, but entries in the database were manually compared to the digitised original in order to ensure as much accuracy in the database as possible. Obvious errors (such as interpreting “Maths 1” as “Maths L” or “Maths I”) were manually corrected at this stage, as were errors in parsing student number and query description.

Often, students would visit a single Hub session with the intention of asking about multiple courses. In this instance, staffers would often record the multiple questions in a single line. However, this increases the complexity of identifying trends in questions on a per-course basis. As such, if, for example, a student asked two different questions about the courses 2A (multivariable calculus) and 2B (linear algebra) in the same session, the staffer could record this as “2AB” or “2A/B”. Such queries were split into the 2A and 2B parts in the database. The short description of the question(s) asked were assigned given the author’s knowledge of the contents of these courses.

When collating the data, several columns of metadata were created in the database. These included the length of the GUID (valid GUIDs can only be 8 characters in length), the semester in which the visit occurred, whether the GUID had been checked for validity, the day on which the visit occurred, and the validity of the date (within the expected range). Of the 1365 queries recorded, no valid GUID could be recovered for 27 entries. No course is recorded for 11 entries, one of which also has an invalid GUID. There are 57 entries with no recorded query. In addition, there are 49 entries with an invalid date that could not be recovered from considering other entries.

5. Data Analysis

There are 1365 queries from 334 students recorded by 49 staffers from October 2023 to August 2024. Here, we discuss some issues with the data collection effort and the data themselves, before exploring what can be learned from these data. There were some issues with the data collection.

5.1 Under Reporting and Double Counting

It was relatively difficult to persuade Hub staffers to take attendance and to return any sheets that they had filled at all, let alone with the fields completed. Anecdotally, more senior members of staff were more likely to be worse at this than Early Career Researchers and PhD students. Further, a surprisingly large number of staff members (post-PhD, salaried) entirely failed to attend their Hub-based office hour at all, or left well before the hour had elapsed. A combination of these two factors led to a large under-reporting rate. To estimate the under-reporting rate, we can compare the Hub sessions on a per tutor basis that should have occurred and compare this to those for which we have managed to collect data. In semester 2, for instance, there should have been 419 Hub sessions over the course of 10 weeks; there are records of 127 having taken place leading to a reporting rate of approximately 30%. This may be slightly exaggerated as students will attend regardless of whether staff attend, so there is a case to be made that staff members who are known not to have attended should be excluded from this figure. Staffers from whom no attendance sheets were returned, collectively assigned to 271 Hub sessions during semester 2, giving a reporting rate of approximately 46%.

Accurate attendance figures are difficult to gauge as a single student may have asked questions of multiple staffers, some of whom recorded the question and some of whom didn't, meaning that the student's attendance was captured but not with as much granularity as was possible. Further, it is known that some staffers are very popular with students, so students seek out these staffers and preferentially attend their hub sessions. Popular staffers also tend to be more diligent at recording attendance data. Hence, from the known attendances it does not seem reasonable to extrapolate total attendance in a given day, as doing so assumes that staffers who diligently recorded attendance were of average popularity. However, in the absence of more information on this matter, we assume that all staffers were equally favoured by all students. As we recorded 1365 student queries, we can reasonably project that there were around 4011 student visits that occurred – on average 26 per hour per session. This estimate is a little high given our personal experiences in the Hub but does not take into account the fact that revision sessions can be very busy or that students do not stay for the whole hour, so the visitor count per session will be higher than the occupancy of the room is at any given time.

5.2 Unrecorded Students

An unknown number of students attend the Hub, not to ask questions about their work, but as a designated study space. As they do not ask questions of a staffer, their attendance is not recorded. Previous attendance data collection efforts have not attempted to distinguish between students attending the Hub in order to talk to a staffer, versus those who attend as a group or solo study session without staff input. It is impossible to estimate the number of students who fall into this category.

5.3 Vague Queries

Many of the findings that can be gleaned from these data will not be widely applicable, as they pertain to the cohorts and courses from which they were collected. The data analysis to detect trends in questions and post-Covid knowledge gaps is complicated by two factors. The first is that there is no control group against which to compare the collection of queries, so there is no way to tell if students are asking atypical questions, other than by experience. The second complicating factor is a vague query summary. Often, if a student's question pertains to a homework exercise, the staffer will record the problem set about which the student is asking, but neglect to include the question number. This issue extends to problem sets distributed via the online learning portal (the query reading 'STACK') and to past paper and mock examination questions. Indeed, there are 20 queries about 'Everything' which is helpful insofar as it informs us that there are students struggling with every aspect of the course but does not tell us if there is anything that they are comfortable with. The issue is further confused by the numbering systems employed in the feedback questions of some courses, wherein Feedback 1 contains the questions FB1 and FB2. There are at least 209 such queries. They are selected as being unhelpful if there is no way to tell from the query itself about what the student sought help.

5.4 Outliers

Of the students whose Hub visits were recorded 160 (of 334) students made a single recorded visit. One student is recorded as attending 65 sessions and asked around 4.8% of all questions that we have captured. The six most popular tutors answered slightly more than 50% of the queries captured (700 of 1365).

Maths 1, a two-semester introduction to topics in pure and applied mathematics, is by far the largest course which benefits from Hub sessions with an enrolment of around 700 students. Given this, it is not surprising that this was the most popular course at the hub with 331 visits in total. As discussed earlier, this figure is likely vastly lower than it should be. It seems unlikely that only half of Maths 1 students visited the hub and each only a single time.

There are many fewer visitors to the Hub for Statistics courses than for mathematics courses. We hypothesise that this is due to the difference in support structures in place for Statistics courses as compared to Mathematics courses, namely that Statistics courses have more contact hours per week as the courses have computer labs in which students are able to interact with staff and seek help on other areas of the course. There are 80 recorded queries pertaining to statistics courses.

There is a level 1 Mathematics service course covering topics in geometry and discrete mathematics for which there were two recorded Hub visits.

5.5 Busy Days

One of the key motivators behind tracking attendance at a drop-in based support room is to ensure that the room that has been booked is sufficiently large to accommodate the students who are likely to attend and there are enough staffers to address their queries in a timely fashion. It is therefore reasonable to ask when the Hub is busy. With the exception of Tuesdays when the Hub was scheduled for the morning in Semester 2 (2024), all Hub sessions took place in the afternoon. The Hub appears to be approximately uniformly busy on all days with the exception of Wednesdays. On 6 of the 12 Mondays in Semester 1 (2023), no student visits at all were recorded. There were a total of 119 recorded visits on Wednesdays across both semesters – 30 of these occurred during a revision session. Thursday is the most popular day on which to visit the Hub with 312 total visits (31.2 per week). This is followed by Monday and Friday, with a total of 286 and 296 visits respectively. Tuesday and Wednesday are relatively unpopular with 164 and 119 visits between October 2023 and April 2024, respectively.

We hypothesise that the pattern of popularity of days is driven by two major factors: summative assessment deadlines and student clubs that meet on a Wednesday. Summative assessments are typically released on a Friday afternoon and are due the following Friday; marking is typically returned on the morning of the Friday after it is due back. We assume that Monday visits are addressing questions about the summative assessment released the previous Friday, the Thursday peak is due to last minute clarifications, and the Friday popularity can be attributed to marking-based queries. This is supported by anecdotal evidence.

Further, we note that many student clubs and societies meet on Wednesday afternoons, and sporting fixtures can require significant travel, meaning that many students cannot attend the Hub on a Wednesday due to prior commitments.

5.6 Trends in questions

The overwhelmingly obvious trend in queries is that students ask about summative assessment and the marking of the same. So far as we can tell, 270 of the 1365 (around 19.8%) questions pertained to summative assessment of some form, whether written homework, an online quiz, or past paper questions. We have determined this by counting obviously named queries such as “FB” or “quiz”. More interestingly however, if a statement is presented in a lecture without proof (because it is unexaminable, for instance) students will attend the Hub in search of the proof. We find it encouraging that students seek to satisfy their mathematics curiosity at the Hub. Other trends in questions were deemed to be too specific to the courses taught at the University of Glasgow to be of interest to a wider readership. Many of these pertain to mistakes in notes, typographical errors in summative assessments, and organisation of course loads.

5.7 Impact on Final Grade

Typically, 70-80% of a student’s final grade will come from a closed-book written exam with the remaining coming from continuous assessment. From the data that we gathered we can separate a cohort of students on a given course into two groups: those that are known to have attended the

Hub and those who are not known to have attended. We are able to compute the mean grade attained in the final exam of students in both groups. We perform this analysis for six of the most popular courses in the Hub based on the total number of visits. We chose to analyse these courses in particular as there are at least 100 visits to each so any conclusions that we draw will be broadly applicable to the cohort. In 5 of these 6 courses analysed, the mean final examination grade of students who attended the Hub was a letter grade higher than non-attenders ($p < 0.01$). In the remaining course, the Hub could not be shown to make a significant impact on grade. Overall, attendance at the Hub is strongly correlated with improved exam performance.

As attendance is not taken in other level 1 or 2 classes, it is impossible to determine whether this is an effect of attendance at the Hub itself or as an effect of active participation in a given course.

6. Limitations and Conclusions

The work described here constituted a significant undertaking. While it was interesting, the fruit that it bore are of questionable usefulness compared to the effort that was exerted in cajoling, collecting, and analysing the data. If there is already a sign-in system in the MSC that does not include the course(s) for which students are attending, it may be worthwhile tracking this in order to ensure sufficient coverage during busy periods.

Due to the number of staffers involved, question summary tracking proves to be difficult and does not seem to allow us deeper insights into the sorts of questions that students are asking, on average. It would probably suffice to ask staffers to report back to the course head if they feel that an unusually high number of students on a given day are asking the same or similar questions.

The limitations of the work discussed here pertain mainly to the paucity of data owing to the difficulty in collecting the data. This issue stems from the large number of people who were asked to cooperate in the data collection effort and is further hampered by the fact that staffers are less likely to collect attendance data when the Hub is busy, because they are engaged in helping students. Further, as mentioned above, it is impossible to determine whether the impact on grade that is correlated with Hub attendance is due to attending the Hub; we assume that students who attend the Hub are more likely to attend their other classes and engage with their courses in general – this will naturally correlate with attainment.

Our findings are in line with those reported in the literature (Matthews et al., 2013), namely that students who seek help see improved performance over those who do not, and that measurement of the effectiveness of mathematics support centres is challenging (Gillard et al., 2011).

However, we are pleased to note that attendance at The Hub correlates with increased student performance. Many students report enjoying the interactions that they have with staff in a less formal setting than in a lecture or tutorial. The Hub appears to have a positive impact on the students who attend and is a useful resource for them.

While the work described here was a significant undertaking, we deem it to have been, overall, worthwhile and are grateful to the many Hub staffers who have aided in the data collection effort.

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WORKSHOP REPORT

Mathematics Support : One-to-one, one-to-few or one-to-many

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Abstract

Many universities operate mathematics support; recent debate has included e.g. whether support should be face-to-face or online. However, another relevant question is how many students should be involved in a session. Students have mentioned that it would be good to have many students together so that they can see the answers to questions that others have. However, academics may argue that it is necessary to quiz students in order to specify the problem and this may not be appropriate in front of other students and these students may not benefit. This study will look at circumstances where maths support should be carried out on a one-to-one basis and occasions where it is beneficial for further students to be present.

Keywords: Mathematics, support, students, numbers.

1. Mathematics Support

Many universities offer mathematics support (Grove, Croft and Lawson, 2020). Croft, Grove and Lawson (2016) note that "The most common provision is the mathematics support centre which typically offers one-to-one support to students on a drop-in basis" with more details provided by (Lawson, 2012). They also note that "Other models of support are used effectively by universities (Marr and Grove, 2010)".

1.1. Mathematics Support at the University of Manchester

At the University of Manchester (UoM), mathematics support has taken various forms over the years. A high point was the period between 2006 and 2009 when a room was preferentially booked for such a service for 20 hours per week and extensively during exam periods (Steele, 2010). This was staffed by various members of staff and Graduate Teaching Assistants and catered for enquiries generated by student projects (and Postgraduate research), staff enquiries etc. as well as questions arising from mathematics units (given to mathematics students and to those on service teaching units). From 2009, and until the present, the emphasis was changed to one anchored at the level of the course unit with each member of staff offering office hours or a drop in session, generally on a weekly basis.

Around 2016, a service was started at the University Library and dealt primarily with statistical enquiries. However, the rapidly-changing environment following the Covid pandemic meant that this service was discontinued in favour of other general means of support.

2. Types of support

The details of support vary greatly between universities e.g. physically based in mathematics buildings, buildings devoted to other disciplines or in student spaces such as unions or support areas (Marr and Grove, 2010).

The different models also vary in that they cater for a wide range of student numbers. Chiriac (2014) notes that "At the present time, there is strong scientific support for the benefits of students learning and working in groups" but qualifies this by stating that "Similarly the question of why some group work turns out successfully and other work results in the opposite is still unsolved" and speculates that "It is important to differentiate between how the work is accomplished in the group, whether by working **in** a group or working **as** a group".

The number of students taking part in a discussion as part of maths support clearly has implications.

3. Models of support

In the experience of the author, one of the most satisfying times in mathematics support (indeed in academic life) is the moment that a student understands a concept in a manner that was not the case at the beginning of the session. Sometimes, this can be a slow and gradual thing while on other occasions, understanding can be sudden i.e. the "lightbulb moment".

Students are likely to spend a lot of time on the resources of the current topic or unit but sometimes the lightbulb moment arrives when realising the implications of something that has been learned in a previous unit or indeed learning to understand the pre-requisite material only as part of the current unit.

An important part of mathematics support is for the advisor to be able to gauge the level of understanding that the student has of the pre-requisite material and often this can only be carried out by means of questions.

Of course, students often "measure" in terms of "how long will I have to wait" and may become frustrated while watching several rounds of one-to-one interactions while waiting their turn. Sometimes, they may even point out that "I had the same question". Of course, if advisors bring watching students into an enquiry, they may (unwittingly) move the session between some of the categories below.

3.1. One-to-one interactions

In this scenario, the student has complete freedom to ask a question and the advisor has complete freedom to clarify the background by asking questions in return. One possible technique is for the advisor to ask the student to start explaining as any misconceptions may surface at this stage. Of course, the student may simply claim total misunderstanding and not attempt a partial explanation. However, it is possible that in this one-to-one situation, a student may be more forthcoming than if other students were watching. The interaction can continue through looking at notes and pre-requisites, trying similar examples etc. and is likely to help the student understand much better than a simple quote of the answer. At the end of the consultation, the advisor can **give** the student any materials written, e.g. printouts of HELM (Helping Engineers Learn Mathematics,) and other resources.

The drawback of this approach is that it is slow, can limit the number of students that can be seen and can be frustrating for students waiting (either in the same room and witnessing or in a waiting room).

3.2. One-to-two interactions

Much of the above applies when there are two students. Generally two students can be sat in such a way to communicate easily (visually – e.g. on paper – as well as vocally). Generally, it will be **one** student who asks the question and the advisor will probably want to know to what extent the second student really does have the same question and to what extent the second student really does understand the subject matter; the questioning can get awkward at this stage.

However, one advantage of a second student is that the advisor can encourage students to explain topics to each other for mutual benefit.

Again, waiting students may not appreciate all of the aspects of this.

3.3. One-to-several interactions

In this case several is defined as sufficiently few that the advisor can be aware of every student and attempt to have some form of interaction with each student. This will be a function of the advisor but generally will be single-figures.

One student will ask a question and the advisor will attempt to answer it. While the advisor can ask questions to the students, and most likely to the student who asked the question, it is not likely that the other students will be asked as individuals but may be asked as a group and significant responses may be rare. The advisor will, no doubt, answer the question but will not get too much of a feel for how many of the students truly understand the response.

3.4. One-to-many interactions

Once the number of participants gets beyond an extent where the advisor can attempt to interact with everyone, the nature of the activity changes again, beginning to resemble a lecture rather than a discussion or tutorial. This kind of activity often takes place in the runup to end-of-semester exams and can involve classes of more than 100 students (and conceivably up to 500 students in extreme cases) at UoM. It may be daunting for students to play an active part (either by raising the original question or by commenting, raising subsidiary questions etc). While electronic communication systems can play a role, they do create an asymmetry of communication and it can be difficult for the advisor to know how much students really do understand. Students may go away confident in that they have seen the correct answer but it is unclear how many of them really understand it enough to tackle similar (or slightly similar) problems.

4. Conclusions

Different models of how to run a mathematics support centre could be said to exist on a spectrum; at one end of the spectrum is a session run for a single student where this single student gets the maximum benefit from the session while the other end of the spectrum represents a session available to a large class but where the emphasis is on benefitting the maximum number of students but at the expense of the benefit being less focussed. However, this article has identified some intermediate ranges where particular types of interaction may take place.

The personal opinion of the author is that more effective support takes place with a smaller number of students. Data on what students perceive to be a more effective session is not currently available at UoM; while this may be a subject of further study, the immediate opinions on effectiveness that a student has on leaving the session may not be identical to the feelings on looking back at some point later during the studies.

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WORKSHOP REPORT

Towards Improving the Accessibility of the Mathematical Sciences for Visually Impaired People

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Abstract

Digital accessibility, inclusion and diversity are increasingly becoming a priority in Higher Education (HE), however mathematical accessibility for visually impaired people remains an area in need of improvement. Gaps in accessibility for visually impaired students can deter them from pursuing Mathematical Sciences at HE level, put them at a disadvantage in traditional assessments and mask a student's mathematical ability. Administration, culture and curricula are among the highest-rated obstacles for visually impaired students studying maths implying that alternative pedagogical approaches and technology are needed to address barriers and educators need to understand the challenges faced by visually impaired students to provide appropriate support. The project undertaken at the University of Glasgow started with a consultation with a variety of institutions, professionals, academics and students. This was followed up with a series of discussion groups and culminated with a hybrid workshop. In this paper we will give an overview of the workshop, our findings and discuss the provision of a consistent support system across programmes which can be adapted around individual needs.

Keywords: Accessibility, Mathematical Sciences, support systems, visually impaired, inclusion and diversity.

1. Background

Studies have shown that gaps in accessibility for visually impaired students can deter them from pursuing mathematical sciences at higher education level (Bell and Silverman, 2019), put them at a disadvantage in traditional assessments and mask a student's mathematical ability (Kwon, 2016). Digital accessibility, inclusion and diversity are increasingly becoming a priority in Higher Education (Mannion, 2023). However, Mannion (2023) indicated that a lack of awareness and internal skills and experiences were the most significant barriers for staff to improve digital accessibility in Higher Education. Indeed, to improve accessibility educationally, educators first need to be able to produce learning material that is accessible, and the student needs to then be familiarised with the accessibility features of the material. Although this may be simple to say, creating just one document that meets the accessibility needs of one individual student is complex. Studies have indicated that administration, culture and curricula are among the highest-rated obstacles for visually impaired students studying mathematics, implying that pedagogical approaches are needed to address visual impairments and educators need to understand the challenges faced by visually impaired students in order to provide appropriate alternatives (Aljundi and Altakhayneh, 2020). Brzoza & Maćkowski (2014) point out that only small number of accessible resources containing mathematics are published, and even with the advancements in technology, we still view accessibility features as 'alternative' instead of the norm. At present, PDF documents remain the quintessential format for scientific publications, and therefore educators are familiar with producing documents in this way. Pierrès et al (2024) found that while academic journals have accessibility guidelines or requirements, the PDF documents they analysed were still generally inaccessible, predominantly due to the lack of tagging, and conclude that accessibility requirements must be a consideration from the start of preparing a document. Structural elements such as headings, page layout, and design (which includes alternative text for images) were found to be amongst the most useful features for visually impaired students in navigating both PDF and Word documents (Singleton & Neuber, 2020).

Mathematical accessibility for visually impaired people remains an area in need of improvement (Klingenberg et al., 2020). Like other educational institutions, the University of Glasgow offers visually impaired student resources like mentoring, assistive technology, exam papers in a preferred format with extra time, course materials in an accessible format, electronic note-takers for lectures, or help with proofreading. Diagrams or data visualisations can be challenging for assistive technology without providing alternative text, which may not always be appropriate in an assessment. LaTeX is a commonly used typesetting package within science disciplines for writing anything from lecture slides to publications. Thanks to open-source projects like MathJax (Cervone et al, 2023), mathematical notation output from LaTeX is now much more accessible, for instance, the ability to transform maths notation to a sentence to be read aloud by a screen reader. A recent addition to the Speech Rule Engine project is the ability to translate a sentence to Nemeth braille. Additionally, tactile data visualisations and diagrams are a difficult problem for Maths, Stats and indeed all Science and Engineering subjects.

1.1. Students living with a visual impairment

Within Scottish Higher Education (HE), the percentage of undergraduate students registered with a known disability increased from 15% in 2018/19 to 21% in 2022/23 (HESA, 2024). This equates to 41,175 undergraduate students with a known disability studying at a Scottish HE institution in 2022/23. Within the University of Glasgow, during the 21/22 academic session, around 14% of undergraduate students were registered with a disability, and from those registered with a disability, 1.4% were registered as 'blind or a serious visual impairment'. Across the University, in 2023, 15% of all students (including postgraduate) and 10% of staff had a declared disability (University of Glasgow, 2023).

Within the School of Mathematics and Statistics, 0.3% of undergraduate students were registered blind or with a serious visual impairment (University of Glasgow, 2024). We note that more broadly, 13% of students within the School were registered with at least one disability with the most common disability being either a learning difficulty (e.g., dyslexia, dyspraxia or AD(H)D) or mental health condition. We refer to the HESA defined categories of disability and the numbers provided here are based on students who identify themselves as blind or have a severe visual impairment and register with Disability Services. We believe that the nature of mathematical sciences is inherently inaccessible, however pedagogically, changes can be made to minimise systemic barriers (Hayes & Proulx, 2024).

1.2. Aims

This project endeavoured to improve the accessibility of Mathematical Sciences for visually impaired people. In the paper, we will address the following:

1. Based on a sample of material containing mathematics and data visualisations, we wanted to understand the perceived accessibility of the document from identified interested

communities which included academic staff, educational and learning developers, support staff and students;
2. If we could produce a mathematical document that meets current legal accessibility requirements, what additional interventions would be needed?

To address question 2, the main minimal requirement is that we meet legal accessibility requirements, and we relied on WCAG2 Guidelines (Web Accessibility Initiative, 2023). More specifically:

- Perceivable - users should be able to accurately see and read content;
- Operable - content responsive and simple to navigate;
- Understandable - easy to use and navigate, contain language understandable to all;
- Robust - compatible with wide range of technology including assistive technology tools.

We also checked against current local University of Glasgow accessibility guidelines for writing content (University of Glasgow, 2023).

2. Project

2.1. Phase One: Consultation with participants (November-December 2023)

The project team established contact with organisations and institutions that were identified as most likely to reach visually impaired people interested in Mathematics and Statistics. Emails were sent to the identified mailing lists and individuals with a survey containing a short example of coursework containing text, mathematical notation and data visualisation(s) compiled using the existing accessibility tool at the University of Glasgow followed by a set of questions (Appendix 6.1). This tool enables text, mathematical notation and alternative text associated with images to be read aloud by a screen reader.

The example coursework, not shared here, based on one of the taught programmes at the School of Mathematics and Statistics, was reviewed to gather examples of plots and other mathematical content found not to be optimised for visually impaired people.

2.2 Phase Two: Consulting with participant during online discussion groups (January-March 2024)

Based on the feedback we received from Phase 1 of the project, our team compiled emerging themes and invited participants to online discussion groups. This allowed us to further understand the main considerations when producing an accessible document containing mathematical content for a student who is blind or has a severe visual impairment.

2.3. Phase Three: Hybrid workshop (20th June 2024)

The University of Glasgow hosted a workshop in June 2024 where we heard from a variety of working groups within maths accessibility. During the workshop, our team presented an updated version of the example coursework that was revised based on the feedback from Phase 2 (Appendix 6.2).

3. Results

The survey was written using Qualtrics (web-based software freely available to University of Glasgow students and staff) after obtaining ethical approval from the College of Science and Engineering ethics committee. In total we received 156 responses. 65% of respondents identified as academics, 25% as developers, 5% as students and 5% as student support.

Figure 1 provides the results from question 3 of the survey (see Appendix 6.1). We found that across all roles identified, around 1/3 of respondents rated the material as ‘Good’ or ‘Average’ and 2/3 of the respondents rated the material as ‘Poor’ or ‘Terrible’.

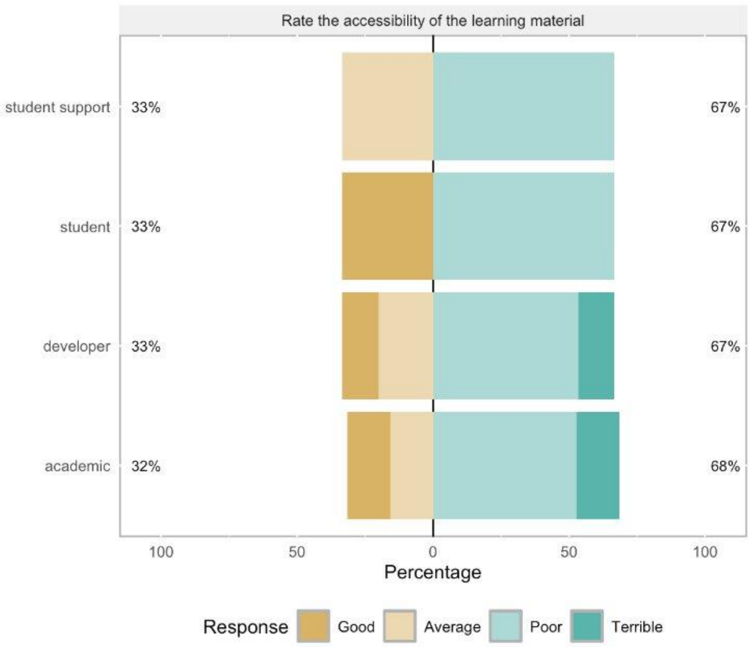

Figure 1. Results obtained from question 3 of the phase 1 survey “How would you rate the accessibility of the learning material”. Respondents are categorised as student support, student, developer or academic (y-axis) and the percentage of respondents who selected ‘Good’, ‘Average’, ‘Poor’ or ‘Terrible’ are provided on the x-axis.

Based on the results obtained from the survey (phase 1) and follow-up discussion groups (phase 2), we categorised responses into the following themes.

Theme 1: Maths. Some respondents mentioned that they either believed MathJax was enabled, or it was not enabled. It was discussed that although educators would typically rely on a compatible screen reader to read mathematics aloud, this may not always coincide with how we communicate mathematics in terms of the language we use. Language in mathematics is a growing area in mathematics educational research (Planas & Pimm, 2024). If students are to experience mathematics verbally, via a screen reader for example, then educators should be considerate of the language used to ensure students can experience mathematics similarly to a sighted person.

Theme 2: Plots. The material provided contained several diagrams and plots (Appendix 6.2) and the issue of providing alternative text was discussed extensively. Depending on the nature of the diagram, figure or visualisation, and indeed what the student should obtain from this, was raised several times. For example, in the instance where the student needs to obtain information from a diagram in order to engage with the material or answer a question then we noted a variety of excellent guidelines from various sources (see for example Diagram Centre, 2015 or Cliffe, 2020 to name just a few). However, when we consider plots or figures, and the expectation of students to both create and interpret plots of data, then the nature of how this information is communicated should change. For example, we would want students to understand the structure of a plot (say a scatterplot of two variables), understand why this type of plot might be useful, know how to interpret the information provided in the plot and be able to create such a plot themselves, as described by Zong et al (2022), see Appendix 6.2 for an example. For R users, the BrailleR package (Godfrey et al, 2024) provides a set of useful tools for breaking down standard plots compatible with screen readers. The question of interpretability of plots for a visually impaired person raised questions about pedagogy and if all plots are necessary.

Theme 3: Legal Requirements. In some cases, participants commented that the materials provided did meet legal requirements whilst others specified that the material did not meet legal requirements. In this instance, we referred to WCAG2 Guidelines (Web Accessibility Initiative, 2023). It was the assumption that participants may have different expectations of what a legally accessible document might look like and we postulate if mathematics educators familiarised themselves with accessing documents in a variety of digital formats that were deemed accessible legally, then it would become second nature (we include ourselves in this bracket as we too navigate this space).

Theme 4: Screen readers. While most participants used screen readers to check if they believed the material could be easily read by their choice of screen readers, this was not true of all participants. In some instances, participants indicated that this can be an effective way to navigate the accessibility of a document.

The workshop had 13 invited presentations, 35 people participated in the workshop in-person and 40 people attended online. The group discussed ongoing projects aimed at improving accessibility in education, such as the use of AI tools, the development of open-source accessibility tools, and addressing the social and emotional needs of individuals with vision impairments in HE. The workshop highlighted the need for a focus on proactively connecting with accessibility groups and networks, user research, proactive approaches to student support, and the future of visual mathematics. The key main takeaways from the workshop were:

- Promoting Accessibility: raise awareness with colleagues to understand accessibility and create a minimal benchmark that can be adapted to meet individual needs;
- Collaborative research: continue to build networks with staff and students, share knowledge and develop new teaching approaches, and improve university administration and pedagogy;
- Software: develop accessible tools that can convert materials created using LaTeX or Markdown, aimed at easing lecturer involvement but with an understanding of document structure;
- Formatting: emphasise individualised support and automation, for example, introduce concepts using 'single line math';
- Visual tools: advocate for interactive tools and sonification to make mathematical education more inclusive and accessible;
- AI and tactile resources: use AI tools to generate accessible content and highlight the effectiveness of tactile teaching resources;
- Support: enhance support, addressing the social and emotional needs for visually impaired students in HE.

We noted that achieving ‘accessibility’ requires bespoke solutions for individuals and therefore there is neither a one-size-fits-all solution nor is meeting legal requirements alone sufficient to support some students as they learn. Figure 2 provides a visual representation of the journey to not only providing a Latex (or Markdown) document in an alternative format (that is alternative to PDF) but illustrates that this is not the end goal, nor should it be.

Figure 2: “make it accessible” - an infographic to illustrate the journey to create a document that meets legal requirements (what we have called the benchmark) but with the acknowledgement that this alone cannot meet the individual needs of the user.

4. Discussion

Higher Education Institutions need to ensure learning materials are accessible not only to support the University’s aims of civic engagement and inclusivity, but they also have legal obligations under the Equality Act 2010 and Digital Accessibility Regulations 2018. The reasonable adjustments duty is an anticipatory and continuing one that is owed to disabled students, regardless of whether it is known whether a particular student is disabled.

Our interpretation of the legislation has two parts— one proactive and one reactive. Coursework handed to students should be converted to an accessible ‘baseline’ HTML document, which has configurable options to assist in the most common impairments such as dyslexia, colour-blindness, visual impairment, and screen reader support. The second reactive part is for students whose needs are not met with the baseline document, is having a trained alternative formats team ready to help. The long-term aim is to fold as much of the reactive work into the proactive HTML document as possible, enabling students to configure their coursework as needed without the delays associated with reactive help from the alternative formats team. The design and structure of documents should adhere to the minimal benchmark with a bespoke solution adopted to tailor learning materials to suit specific needs.

Through the growing interest and literature on mathematics accessibility, the outcomes of the workshop advocate for educators to think about the structure of all learning content from its inception such that it can meet the needs of the learners as opposed to the status quo, see for example the JISC Accessible Maths Working Group for a collection of resources from a variety of institutions (JISC Accessible Maths Working Group. 2024) and highlight Chirun for creating flexible material from a LaTeX or Markdown sources (Chirun, 2025).

The concluding remarks from the workshop were that meeting accessibility needs is an interdisciplinary problem that requires support for students on a variety of levels. Miesenberger et al (2023) involved expertise in disability, mathematical software and interactive proof assistants. Joy et al (2024) is a collaboration between a blind maths student, a tutor and a learning technologist. The student experience should be at the core of these endeavours and therefore understanding how students experience learning. While Dogucu et al (2023) discuss the experience of visually impaired students during lecture interactions, Croft (2020) describes bureaucratic, accommodation and social interactions to be significant barriers for visually impaired students at UK HE institutions, all of which affect all students before any interaction with learning material. Manitsa & Doikouv (2022) further emphasise the need for social support, both from staff for academic support or inclusion and from peers for social acceptance.

5. Acknowledgments

We are grateful to everyone who participated through the several stages of this project and attended the workshop in June 2024 at the University Glasgow. We thank the Edinburgh Mathematical Society, the Institute of Mathematics and its Applications and the Glasgow Mathematical Journal Trust for supporting and funding the workshop.

6. Appendices

6.1. Survey questions

The survey contained the following questions

1. How would you best describe your current role?
2. Do you consider yourself blind or have a severe visual impairment uncorrected by glasses?

Based on the same learning material provided to you (participants were given a link to click)

3. How would you rate the accessibility of the learning material rated from Terrible to Excellent? (see Figure 1).
4. Please describe any positive features of the learning materials (open question).
5. Please describe any features you believe would cause barriers in learning for someone with a severe visual impairment (open question).

6.2. Sample material

Below you can find a link to the material presented to workshop participants.

Sample Material.

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CASE STUDY

Building mathematics students' careers knowledge and confidence through an extra-curricular industrial challenge

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Abstract

The Department of Mathematical Sciences at the University of Liverpool has a well-stablished strand of embedded employability activity in the mathematics curriculum spanning every year of undergraduate study. To supplement this curricular offer, an extra-curricular activity was offered to students in 2024. This article will provide details on the development of the extra-curricular activity set by a major employer based in the Liverpool region. The activity challenged students to work together in groups to consider the wider societal and cultural issues in working with mathematics for a major international business. A study was conducted with the participating students which aimed to investigate whether the activity had enhanced their knowledge and confidence about opportunities for mathematics graduates. The survey results demonstrate that participants were more knowledgeable about opportunities for mathematics graduates and developed confidence in their skills development through participation in the activity.

Keywords: active learning, group work, employability, skills development.

1 Introduction

A strand of embedded employability has been developed over several years in the mathematics programmes at the University of Liverpool. The aim of this strand is to provide students with opportunities to develop key employability skills as a core part of their degree. Embedded activity has been shown to be an essential element in promoting student engagement with such development (Bridgstock, 2009).

As part of this development, group tasks for simulated clients and open-ended project briefs have been incorporated into module assessment. A key feature of this strand is the final year capstone module Professional Projects. This module tasks students with working in groups to investigate authentic projects set by industrial partners. The structure of the embedded strand is such that students build their confidence and awareness of skills through the years of study and then have the opportunity to work on live projects set by real employers. During the development process, care was taken to ensure that the novel assessment approaches and tasks were in line with the module content, and that the new elements were appropriate forms of authentic assessment in the context. Throughout the strand, there is an emphasis on the benefits of reflection - students are required to reflect regularly in written pieces and in digital stories. The aim of this element is to encourage awareness of skills development and the articulation of skills acquisition.

2. Extra-curricular activities for employability

Extra-curricular activities take place outside of formal, timetabled curricular activity. Students are encouraged to participate in such activities as there are a number of possible benefits – employers want to see evidence of skills development and examples of the utilisation of these skills, and extra-curricular opportunities can provide this (Jackson et al., 2024, Waldock, 2011). There is evidence that extra-curricular activities have some positive impact on the enhancement of employability skills

(Ramesh et al., 2014, Moxey and Simpkin, 2021). Many authors with experience advise caution in making extra-curricular activities the central focus of employability development (Cranmer, 2006). The curricular offer should be prioritised as this is where students will focus their attention - development of these skills should be a formal part of undergraduate degree programmes. Extra-curricular activities can help to supplement embedded activities with opportunities for students to explore societal, commercial, or interdisciplinary perspectives on topics.

One of the main challenges with extra-curricular activities is understanding and compensating for barriers to engagement. As the activities are not formally a component of students' degree courses, the intended benefits must be clearly stated for students. Some authors identify financial pressure, lack of confidence, and study or work commitments as potential barriers to engagement with extra-curricular activities. It has been noted that students prioritise extra-curricular activities which offer a financial incentive, and those where networking and skills development are clearly available (Jackson et al., 2024).

3. Development of the challenge

An extra-curricular mathematics challenge was proposed as a Faculty of Science and Engineering Educational Enhancement Project. The faculty offered financial support to run the activity in the 2023/24 academic year. To add authenticity to the activity, an employer partner was sought to collaborate in setting an appropriate mathematical challenge for students. It was decided that the challenge should run over several weeks to provide time for students to conduct some analysis and collate findings. To promote the development of communication skills and teamwork, the challenge was proposed as a group task. Following discussion with the employer partner, it was decided that the output would take the form of a short group presentation as this is what would be expected in the business. The intended format of the challenge is given in the Table 1 below.

Table 1 – Format of the challenge.

Session	Activities
Week 1	• Ice breakers with student groups • Introduction to the context and challenge question from employer partner
Week 2	• Information session on mathematical careers at the organisation • Time for project work
Week 3	• Support with presentation planning • Finalising project findings
Week 4	• Presentation and celebration session • Networking with the range of employers in attendance

The employer who collaborated on the challenge is a large international business based locally. The proposed challenge asked students to consider proposals for product launches in two different territories. Students were supplied with data on the costs of ingredients for products, and data from customer focus groups in the two territories. Thus, the challenge asked students to consider a range of commercial factors in their proposals. It was hoped that this approach would demonstrate to students that the analysis is only part of a successful proposal, and they would need to spend time researching and appreciating the compromises needed in reaching a viable solution in the given context.

Due to the extra-curricular nature of the challenge, the timing of the activity was crucial. It was decided that the challenge would take place at the beginning of a semester (before students become focused on continuous assessment for their taught modules), and that the in-person sessions for the challenge would take place on Wednesday afternoons when there is no timetabled teaching activity. It was hoped that this approach would provide the best chance for students to engage with the opportunity. A PC lab on campus was booked for the sessions as the range of software available on campus PCs was useful for the analysis.

To make the challenge appealing to students, a prize (in the form of a gift voucher) was offered to the group deemed to have delivered the best final presentation. This was promoted as a key part of the challenge during recruitment. Lunch was also provided to students before each session. The opportunity was advertised to students in November 2023. Thirty-five students signed up for the challenge - eighteen Year 1 students, eight Year 2 students, eight Year 3 students, and one Year 4 student. The breakdown of the student enrolment can be seen in Table 2. For most programmes, just under 10% of the eligible cohort enrolled on the challenge. This was a good outcome for an optional, extra-curricular activity in the first year it was offered.

Table 2 – Student enrolment on the challenge by degree programme.

Degree Programme	**Number of students**
Mathematics	12
Mathematics and Economics	5
Actuarial Mathematics	5
Mathematics with Finance	3
Mathematics with Languages	2
Mathematics and Statistics	2
Mathematical Physics	1
Theoretical Physics	1
Mathematics and Philosophy	2
Mathematics and Computer Science	1
MMath	1

As 18 of the students were in Year 1 and had thus only completed one semester of university study at the time of the challenge, care was taken in forming the groups for the task. Five of the students in Year 3 had studied the capstone Professional Projects module in semester one and had thus tackled several projects set by employers already. These students agreed to be group leaders and time was taken to ensure that groups were balanced in terms of experience and skills.

As the task was open-ended, this provided scope for all students to propose ideas on the approach. Similarly, conducting an analysis of the data provided was only part of the challenge, and research into the different territories for the products was necessary. This aspect of the task provided space for all group members to contribute. Those who had much more experience in data analysis could focus or lead on the analytical work, while others could research the context for the problem and identify where the analysis alone might be insufficient to determine a useful solution.

4. Evaluation

As a formal evaluation of the activity, two surveys were administered over the course of the challenge. The aim of the study was to determine whether experience of the activity enhanced participant knowledge about careers for maths graduates, and whether the activity had any impact on participant confidence in several skill areas.

All students who signed up for the challenge were invited to participate in the study. Participant Information Sheets were distributed in advance of the challenge and students could choose whether to opt into the study or not. The first study was administered at the beginning of the first session to determine a baseline for participant careers knowledge and skills confidence. The second survey was administered in the final session of the challenge. The initial set of questions in the surveys were identical to allow for comparative analysis, while there were some additional questions in the second survey to allow participants to expand on their experiences of the activity. Twenty-four students participated in the study (a response rate of 69%).

Students were asked to respond to a series of statements on a 5-point Likert scale. Under this scale, “1” corresponds to “strongly disagree” and “5” corresponds to “strongly agree”. The statement on skills development was interesting as the comparison from Week 1 to Week 4 in Figure 1 demonstrates. Considering responses to the statement “I feel that I am developing the skills needed for graduate employment”, the mean in Week 1 was 3.04 and this increased to 3.39 in Week 4. The box plot clearly documents the positive shift in perception of skills acquisition over the challenge. 35% of student participants felt they were developing important skills for graduate employment in Week 1 and this increased to 55% in Week 4.

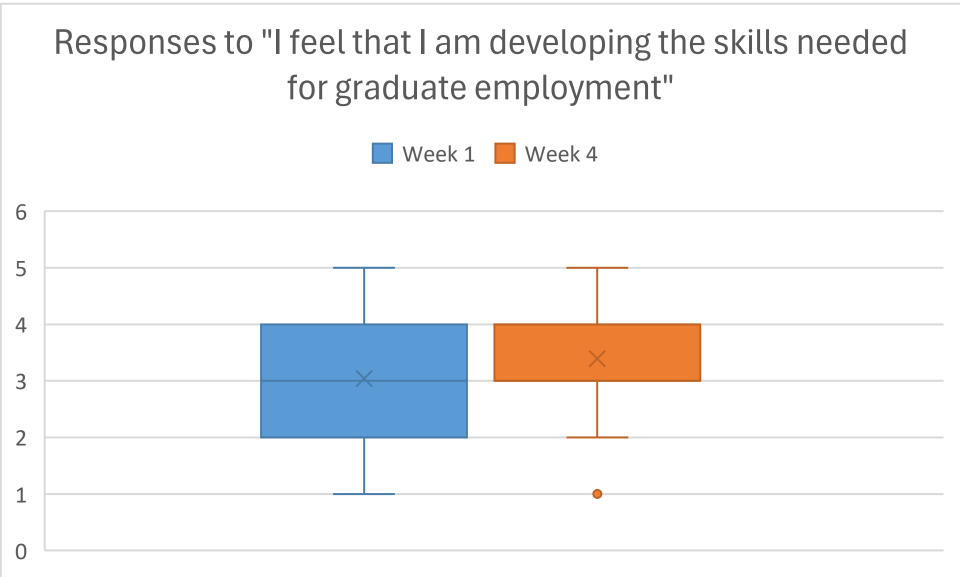

Figure 1 – student perceptions of their skills development.

One of the aims of the activity was to inform students about the range of mathematical careers available. The session delivered by employer representatives in Week 2 presented details on such opportunities explicitly. As can be seen in Figure 2, there were some improvements in awareness of career opportunities over the course of the challenge. The mean response to this statement was 3.29 in Week 1 and this improved to 3.67 in Week 4. 54% of participants felt aware of career opportunities open to them in Week 1, and this increased to 71% in Week 4.

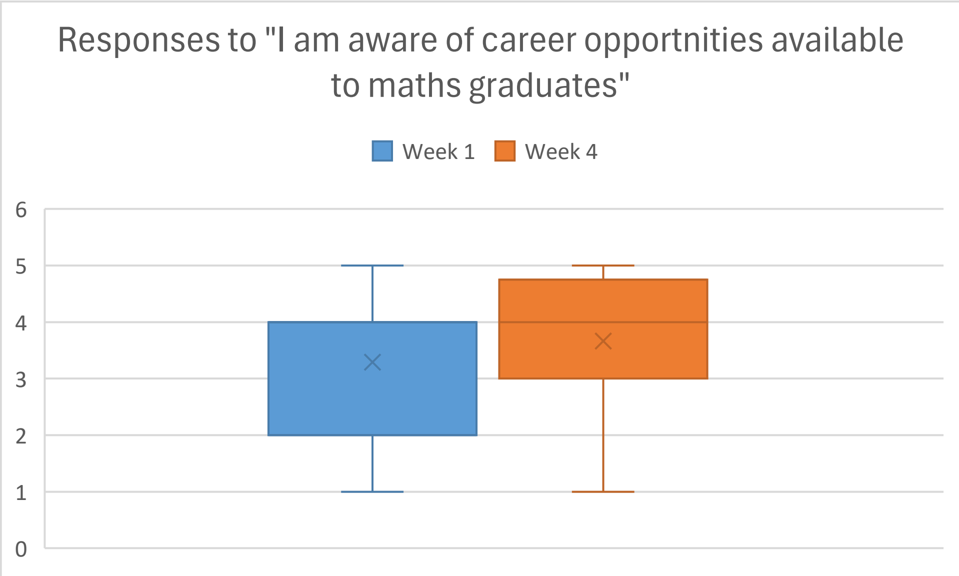

Figure 2 – student awareness of career opportunities.

Participants felt that the challenge provided them with some useful insights into how mathematics is applied in industry. As can be seen in Figure 3, 88% of participants felt that the challenge provided such insights.

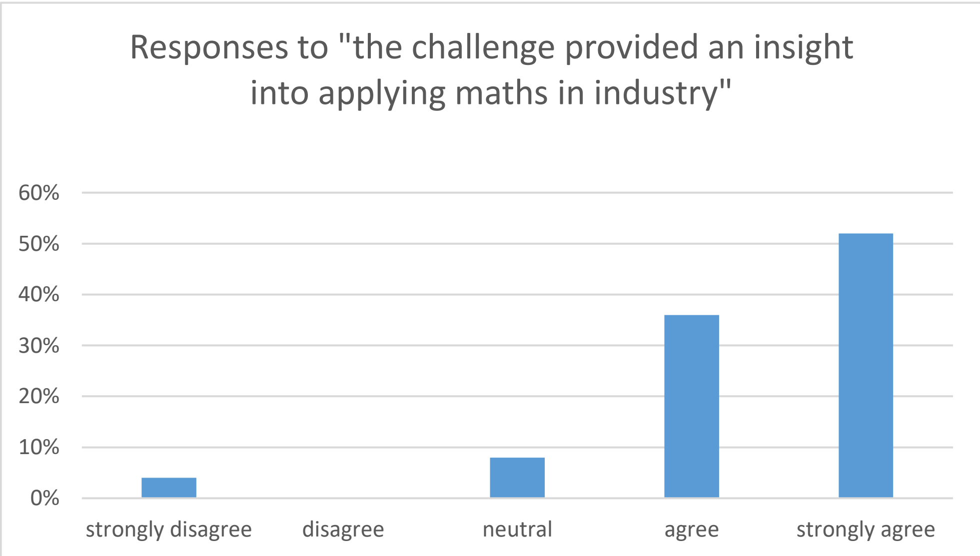

Figure 3 – student views on insights into applying maths in industry.

Over 90% of participants felt a positive impact on their communication skills. As the key output of the challenge is a group presentation, this finding indicates that participants felt positive about the group work and presentation elements. This is especially encouraging as for many students this was the first time they delivered a presentation.

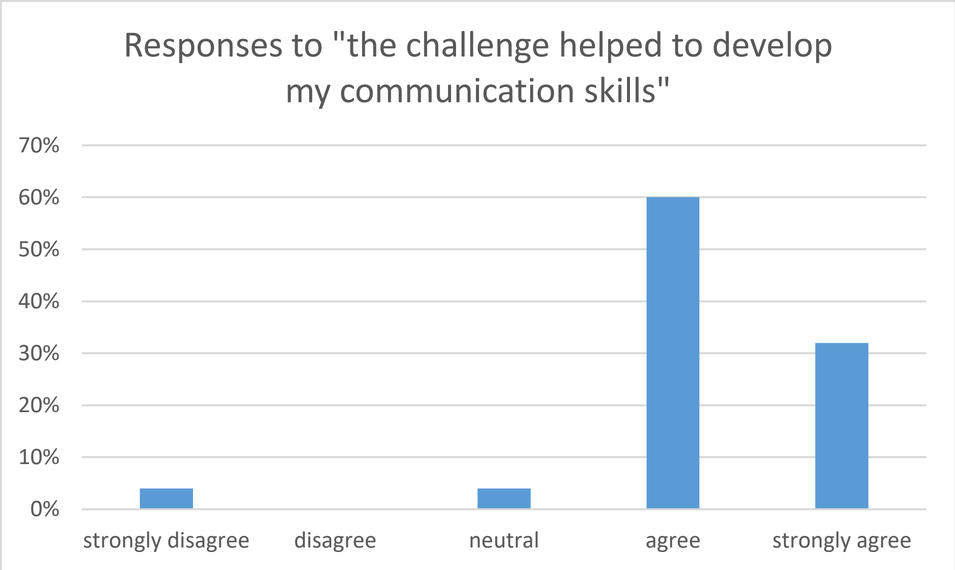

Figure 4 – perceived development of communication skills.

Free-text Comments

In the Week 4 survey, participants were presented with two optional free-text response questions. These asked what (if anything) was most beneficial about the challenge and what improvements could be made to the challenge in the future.

Those who responded to the first question (on benefits of the activity) highlighted the opportunity to enhance their communication skills. Specific responses to this question include:

> *“The chance to apply my maths skills and chance to learn from others.”*
>
> *“The presentation experience”*
>
> *“Being able to describe results from maths in a way that was understandable by people in other aspects of a business.”*

When asked to identify any improvements which could be made, some participants indicated a desire for more guidance on how to tackle the problem:

> *“A bit more guidance as it’s very vague especially for students with no experience.”*
>
> *“slightly more information in the brief as to how certain data was collected.”*

It is not unexpected that some participants noted the lack of explicit guidance in this task when compared to structured problems in traditional mathematics modules. Another aim of the task is to expose students to messy, authentic problems from industry.

5. Discussion

The findings from the study indicate that there are benefits to offering mathematics students extra-curricular activities. The format of the challenge provided scope for students to learn about many different areas where mathematics is used and also areas of business where their analytical and technical skills are valued. This is especially relevant for mathematics students as there are many different careers available and students are not always aware of the variety of mathematical roles in organisations. In addition, the group work element was particularly effective here as the experienced Year 3 students who had studied the capstone Professional Projects module were able to act as mentors and group leaders. The support and reassurance offered by these senior students provided encouragement for others to build their confidence and engage successfully with the activity, while also providing the Professional Projects students with leadership experience. This reinforces the important point that the embedded offer must take priority before any additional activities outside the curriculum are considered. The extra-curricular activities can supplement but should not be the focus of employability skills development – space must be made in the curriculum for embedded employability initiatives and careful consideration must be given in matching these activities to the stage the students are at in their degree experience, and the appropriateness of the specific module(s) where the activity will be introduced.

As identified by the results from the study, a significant draw for participants seems to have been the opportunity to enhance their skills development. When asked to identify the best thing about the challenge, students singled out the experience of giving a presentation and communicating mathematical work to a business audience. This was a novel aspect of the task for most students and the fact that many identified this as a stand-out benefit is very reassuring. Once again, an important element contributing to the success of the presentation element is the placing of Year 3 Professional Project students as group leaders and mentors. They made what could be a very intimidating prospect (giving a presentation) a valuable learning opportunity and were able to share their tips and experiences of this form of communication with their teammates.

In the future, it is hoped that similar activities can be offered to students. As noted previously, there can be more barriers to engagement with extra-curricular activities and so every effort must be made to highlight the potential benefits to students, and to identify a suitable time in the semester when students may have space for the initiative.

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RESEARCH ARTICLE

Public Engagement for Student Empowerment

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Abstract

The ability to disseminate and communicate densely mathematical and technical material to a non-technical audience and coworkers is a key employability skill for mathematics graduates. As educators it is important that we consider how to bridge this gap and how we can embed these skills into already tightly packed programmes. At Middlesex University we have long believed in embedding communication skills in our undergraduate mathematics programmes to empower our students from diverse backgrounds. Importantly, while these students are with us, we also present them with the opportunity to work as mathematical ambassadors and apply these skills in-situ during outreach and public engagement events. These events include SMASHFest, Big Bang, Thorpe Park, World Skills, Teen Tech, and MDX STEMFest. This increases their confidence and knowledge of mathematical topics further while enhancing their employability, communication skills, and social capital.

Keywords: Communication, outreach, student confidence, affective domain.

1. Introduction

The demands placed on mathematics graduates from employers have changed in recent years. Increasingly, graduates are expected to have programming and communication skills along with more traditional skills such as problem-solving. While mathematics students are well regarded when it comes to working with highly technical material, they are perhaps less well known for their communication skills (Groves, 2012). These shifting demands and the change in the post-pandemic education landscape have caused us to rethink how we approach the design of the mathematics programmes at Middlesex University (Jones, et al., 2022).

Throughout this process our goal was to design a suite of mathematics programmes that would allow our students to demonstrate their ability, meet the shifting needs of the graduate job market, and remains mathematically rigorous. Our design decisions were shaped by knowledge of the features of our student body.

The demographics of the Middlesex student body have particular challenges: 59% of full-time undergraduates are from IMD quintiles 1 and 2 and 38.5% were eligible for free school meals (Office for Students, 2024). Digital poverty also presents a significant obstacle for success of students in a job market where digital skills are increasingly in demand. Recent research has shown that students from backgrounds such as these a significantly disadvantaged in closed book exam assessment when compared with their peers who do not have these difficulties (Megeney, 2016).

Middlesex University has always placed a heavy emphasis on applied, practical skills that prepare its graduates for the workplace. This gave us license to radically rethink our approach to assessment and consider what employability skills are required by maths graduates in today's job market. There is a danger that universities have placed too much significance on examining students' ability to apply various techniques in familiar settings (Crawford, 1996). In comparison, not enough time is spent on teaching other soft skills such as communication and problem solving (Borovik and Gardiner, 2007), which are vital to a successful career as a mathematician.

These observations led us to two innovations in our mathematics programmes: firstly, given our students are from demographics that tend to be disadvantaged by examinations we decided to focus exclusively on authentic assessment to assess the students. Middlesex University (Centre for Academic Practice Enhancement, 2022) defines authentic assessment as follows:

- Is realistic;
- Requires judgement and innovation;
- Asks students to 'do' the topic;
- Replicates or simulates the context in which adults are tested in the workplace;
- Assesses the student's ability to efficiently and effectively use a repertoire of knowledge and skills to negotiate a complex task;
- Allows opportunities to rehearse, practise, consult resources, and get feedback.

Our interpretation of this definition is that students should be given the opportunity to enhance their employability skills while still testing their mathematical ability in their assessment (Masterson, et al., 2024). Secondly, we sought ways to integrate problem solving, communication, and outreach to enhance students' confidence and employability skills.

In this paper we will examine students' perceptions of how these activities have contributed to their development as mathematicians. We conducted a survey of student's attitudes towards the communication/outreach elements of their degree programme. This was part of a larger survey that included the quasi-pre/post measure of students' attitudes towards mathematics using the MAPS (Code, et al., 2016) the results of which are to appear in (Jones, et al., 2025).

1.1. Communication

When we originally designed our undergraduate mathematics offerings, we attempted to get students to engage with all aspects of mathematics, going beyond mathematical tasks and techniques, to develop a range of skills valued by students and employers (Megeney, 2016). One of the skills that we identified was communication skills.

The ability to disseminate technically dense material and communicate it to colleagues and other stakeholders is a skill increasingly in demand skill among graduates (Megeney, 2016). Unfortunately, this is also something mathematics graduates are not particularly well known for (Groves, 2012). However, communicating mathematics is an important part of being a mathematician (French, et al., 2023). Communication is integral to finding flaws in others' arguments and conveying your own individual reasoning (Borovik and Gardiner, 2007).

In the first iteration of the programmes, communication skills and other soft skills were catered for in a weekly programme workshop entitled Engaging with Maths. However, these skills were not assessed in this workshop.

When the undergraduate programmes were being revalidated for the academic year 2022-23 it was decided that communication would be embedded throughout the programme. In particular, it has a dedicated level 5 module *Problem-Solving and Communication*. This module does not seek to introduce any new mathematical techniques but rather encourages students to draw from techniques developed in other modules to solve unfamiliar problems then consider their reasoning in selecting their chosen methods and communicate this to lecturers and their peers.

In seminars and workshops students are encouraged to discuss the problem-solving techniques with one another with the goal being to solve a given problem. This allows students to evaluate each other's reasoning, see the problem from different perspectives, and learn to communicate their reasoning in a manner that is coherent to their classmates and lecturer. In this module students explore a variety of different ways to communicate their reasoning including report writing, in-person presentations, multi-media presentations, and oral examinations.

Mathematics Engagement Brief

This communication brief requires you to develop an activity or resource that could be used to promote, or engage people with, mathematics.

This can be done either by
- a short mathematics activity with feedback sheet,
- a blog (1000 - 2000 words or multimedia equivalent), or
- a short video such as a screencast (2.5 – 4 minutes).

Figure 1: Communication assessment brief

Figure 1 is an extract from one of the briefs for a communication assessment. Here students are asked to develop a maths related resource or activity. The students are given several options on what form they want the resource to take. Encouraging the students to carefully consider how they want to communicate, and what would be the best form of submission for their resource, further enhances their communication skills and their confidence.

The communication skills that students were introduced in the Problem-Solving and Communication module are then further embedded throughout the programme. Often this takes the form of essay, report writing, and project-based assessment in modules such as *Data Mining*, *Graph Theory*, *Galois Theory*, and *Cryptography and Blockchain*.

It is vital that students see that communication skills are embedded in multiple places in the programme so they understand that communication is a vital part of their mathematical education that should not be ignored and will be beneficial to their career prospects.

1.2. Outreach activities

The maths team at Middlesex University has long been involved in outreach events. In the past staff and students have either taken part in or led the following outreach events SMASH Fest UK, Big

Bang, Thorpe Park, World Skills, Teen Tech, New Scientist Live and MDX STEMFest. These events range from having hundreds of visitors for the MDX STEMFest to tens of thousands for New Scientist Live. Our motivations behind participating in these events are two-fold. First, many of these events are aimed at increasing participation and interest in STEM in socio-economically disadvantaged areas.

Secondly, and more relevant for the present paper, we encourage our students to participate in these events. The goal being that by being exposed to an audience whose mathematical experience is different, and usually less extensive, than their own will deepen their communication skills and build their confidence. The environment of these outreach events is less controlled than that of the classroom. In the classroom students are communicating with their peers or their lecturers, i.e. those who have a similar level of knowledge in mathematics or greater than the student. At these outreach events students will need to interact with a range of people with a variety of backgrounds and abilities in mathematics.

Interactions such as New Scientist Live and the STEM festival require the students to consider how they can effectively communicate mathematics to a non-mathematical audience. The students will have to think on their feet and consider the object of the outreach event from several different angles in order to successfully communicate to a diverse audience including members of the public, children of all ages, students and aspiring students of scientific disciplines and science professionals. Many of our students will work in jobs where they may be one of a small number of people who will have a maths degree, or a degree with significant mathematical content. Our maths degrees are designed to prepare our graduates to be the mathematical expert in their professional team or organisation. Therefore, the ability to communicate with non-mathematicians is just as important communicating with fellow mathematicians. These kinds of interactions will also increase the students' confidence in their communication and ability in mathematics (Megeney, 2016).

2. Methodology

We conducted an anonymous survey of current students and recent graduates of our undergraduate mathematics programmes between July and August of 2024. The survey was based on the Mathematical Attitudes and Perceptions Survey (MAPS), developed by Code, et al., (2016) and discussed in detail in Jones, et al., (2025). In our questionnaire, students completed (a subset of) the MAPS, reflecting on their attitudes before university, then answered specific questions about key elements of our learning and teaching approach, before completing (the subset of) the MAPS a second time reflecting on their current attitudes.

In this paper we report on the specific questions about the communication and outreach elements of our learning and teaching approach. Each student rated the statements "Outreach activities made me more confident", "Outreach activities increased my anxiety", "Outreach activities helped me prepare for my professional career", and "Outreach activities are an important part of mathematics", and similar statements for "communication activities". They were also given a free text response where they could tell us about their experience with these activities. We were interested in the perceived impact of these activities on students' confidence, anxiety and whether the students consider communication and outreach as central to mathematics. For the results of the MAPS questions see Jones, et al., (2025).

When conducting our analysis we encoded students' responses to the Likert scale questions on a -2 to 2 scale. Then to summarise we simply took the average. The results of the anxiety questions were multiplied by -1 so positive score have the same interpretation across questions.

3. Results

In their responses students were generally very positive towards both the communication and outreach activities.

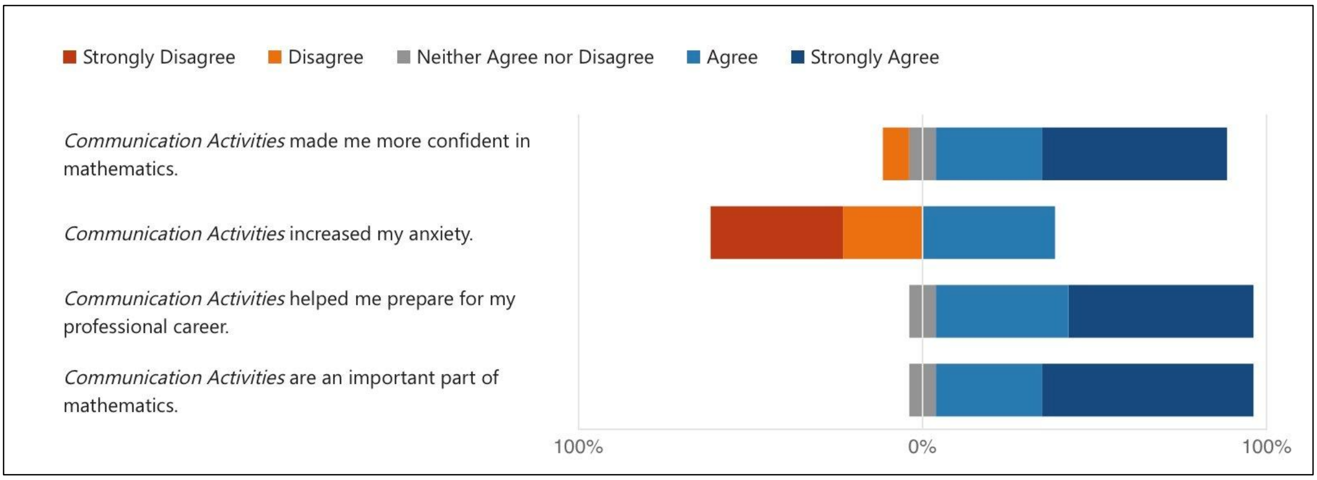

Figure 2: student attitude towards communication activities

From Figure 2 it can be seen that not only did the communication activities make them more confident in their own mathematical ability but the students also saw these kinds of activities as vital for preparing them for their professional careers. Some recent graduates left comments like:

"This allowed me to improve my presentation skills as it exposed a weakness of mine which I had previously believed was not an issue for me. This realisation inspired me to improve on my speaking skills."

Another recent graduate contacted us separately to highlight the impact these activities have had on their career trajectory:

"I just wanted to let you know that I've gotten my graduate job as a data analyst! Specifically, they were impressed with my communicating mathematics project."

These responses are typical of the responses we have received regarding the communication activities on the degree programme.

It is also clear from Figure 2 that not only do students view these activities as important for themselves and their own career, but they also view communicating mathematics as an important part of mathematics in general. It is worth noting that this was all achieved without significantly impacting the students' anxiety.

The data for the outreach activities paint a similar picture as can be seen in Figure 3:

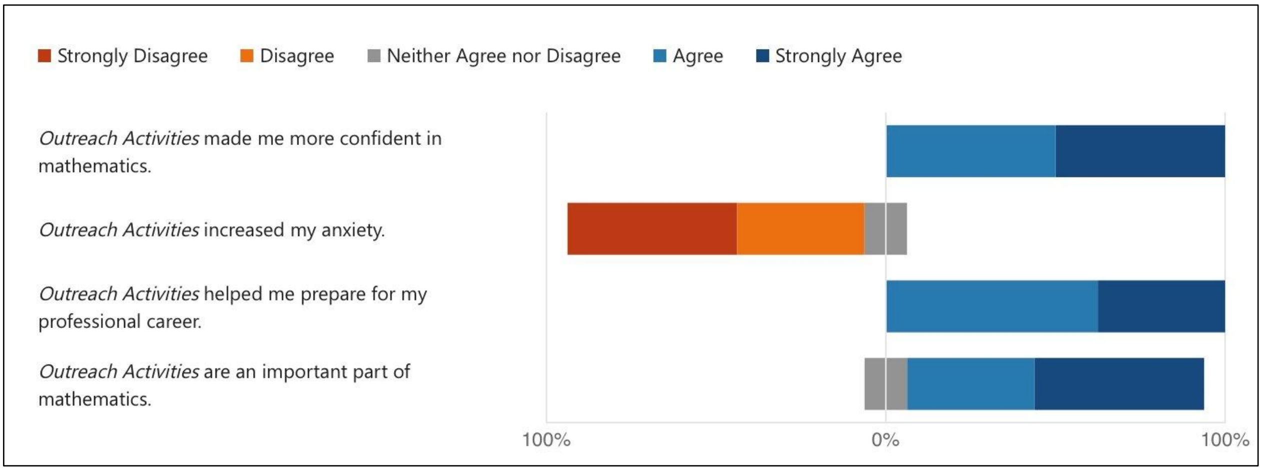

Figure 3: Student attitude towards outreach activities

Again, we see that students generally responded that they found these activities beneficial for their own confidence in mathematics and preparing them for the working world. They also view these activities as an important part of the subject area, and they do not appear to increase student anxiety. We have had several students comment on what exactly they find beneficial about these events:

"By facing the public for hours at a time and having to explain mathematical concepts to people of varying age groups, this allowed me to improve my public speaking and improved my ability to adapt to various situations."

"During World Skills, it was great to be able to express my passion for Mathematics and impart that to the general public. It made me more confident in my mathematical knowledge as I knew the content and it helped me form a coherent answer that was easily digestible."

"Working with a crowd and having the lecturers around to correct me if I'd said something wrong made it easier for me to speak about different topics within maths without worrying about saying this the wrong way. Such activities helped me grow as a mathematician by offering confidence in myself and what I know to be true."

The common thread here is growth in confidence students obtained from participating in these activities.

Figures 2 and 3 provide an overview of how the participants feel about these activities in general. As we've observed, overall, the results for communication activities are the same as those for outreach activities. However, we include a side-by-side jitter plot for communication and outreach activities so we can compare the distribution of individual responses for each of these activities.

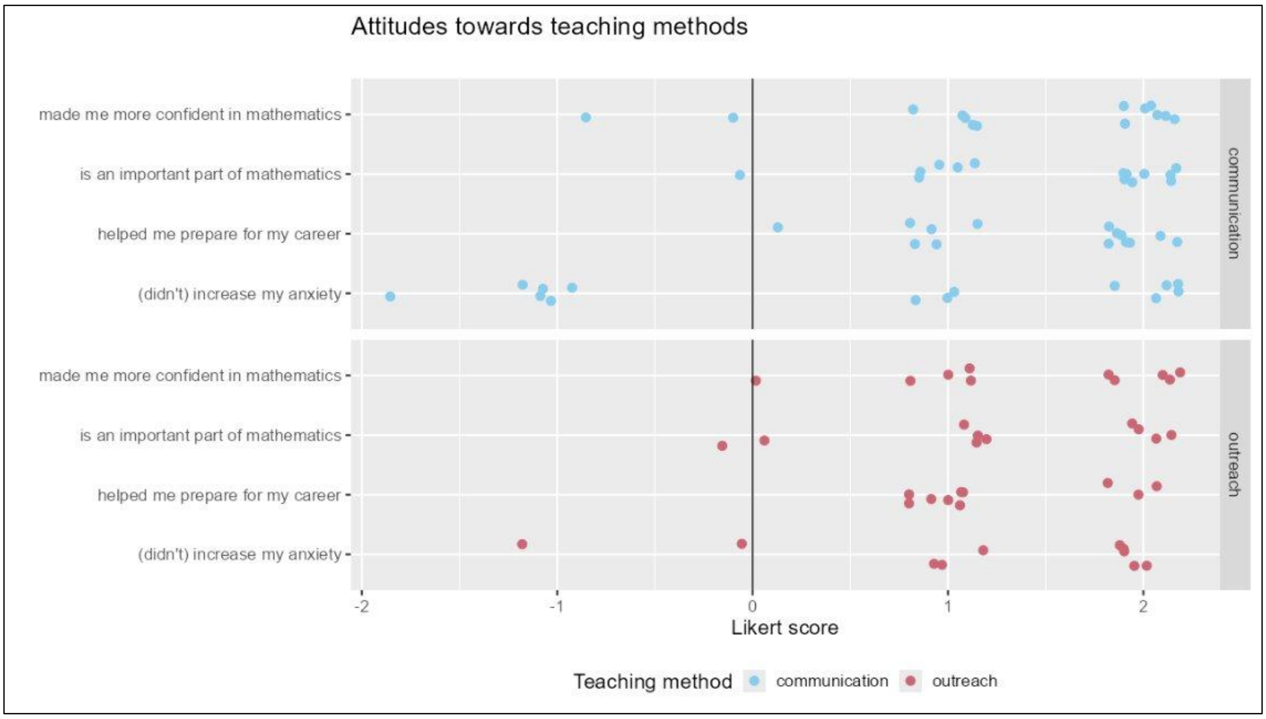

Figure 4: Comparison of individual responses. Each point is an individual student response and are jittered to prevent overplotting.

Table 1: Mean Likert scores of interventions

Question	Intervention	N	Mean score	SD
[Intervention] activities made me more confident in Mathematics	Communication	14	1.29	0.914
	Outreach	10	1.40	0.699
[intervention] activities (didn't) increase my anxiety	Communication	14	0.43	1.505
	Outreach	10	1.20	1.303
[intervention] activities helped me prepare for my career	Communication	14	1.50	0.650
	Outreach	10	1.30	0.483
[intervention] is an important part of mathematics	Communication	14	1.50	0.650
	Outreach	10	1.20	0.789

For the majority of questions there doesn't appear to be any notable differences in the responses for questions concerning communication activities when compared to their outreach counterpart.

The notable exception to this is the questions concerning student anxiety. From the Figure 4 we can see that the communication activities seemed to cause more anxiety than the outreach activities. This is further backed up by the difference in the average scores for both interventions on this question. There are a number of speculative reasons we could offer for this. One is perhaps it is due to the difference in audience between the two activities. For communication activities students often have to present in front of their classmates and lecturer. Whereas for outreach activities the audience is usually members of the public or school children – an audience the students may find less intimidating due to the differing levels of expected mathematical knowledge. Another possibility is that for the communication activities students would have to prepare something in advance of the activity perhaps adding to the anticipation and pressure of the activity. For outreach activities students usually aren't required to prepare anything in advance.

4. Discussion

On completing a maths degree, graduates have many options from continued study in mathematics, or the scientific, financial or technological disciplines that a mathematics background affords, to the wide variety of careers that mathematical skills and knowledge are valued in. Fundamental to these is that our graduates have confidence in their own mathematical ability and are able to talk about mathematics effectively both to peers and a non-mathematical audience.

These aspects of being a mathematician are often overlooked or forgotten about when we design assessment that mainly focuses exclusively on application of various techniques solve problems or prove statements (Borovik and Gardiner, 2007). We have taken an approach that builds communication and outreach into our maths programmes to give students and opportunity to develop their communication skills and confidence in their own ability.

The results are extremely positive: students who have participated in these activities found them to be hugely beneficial for their confidence and preparing them for their career while not having an overly negative impact on the student's anxiety. An interesting point of difference is that the communication activities do seem to have a more negative impact on student anxiety than outreach activities.

5. Future work

As part of an ongoing outreach project we're running in partnership with the Science and Technology Facilities Council (STFC) we're planning several school cocreation events. The project aims to engage school students from disadvantaged areas with STFC activities. Through these cocreation events school students will see how mathematics applied to space travel.

The end product will be an interactive game in which school students can design their own planet, add this planet to their class/school solar system, and explore this universe by solving mathematically themed puzzles.

We plan on recruiting our own students to work at these cocreation events as Mathematics Ambassadors engaging school student and the public in these activities. These cocreation events will take place at science festivals such as New Scientist Live, MDX STEM Fest, or similar and through school visits, particularly schools in disadvantaged areas. At the events we will deliver a number of creative and engaging maths themed activities. Our maths students will be engaging the audience in the activities while also imparting their knowledge of the mathematics that underpin the activity. The goal for our maths students is to enhance their communication abilities and social capitol through these events. To date students have worked at MDX STEM Festival and New Scientist Live and engaged school students in creative activities like imaginative planetary design and relate them to concepts such as orbits.

Next, our students will visit STFC funded facilities to learn more about their work and accompany us on several school visits over the coming academic year.

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CASE STUDY

Whole Student Cohort Co-creation of Industry-Based Assessments in an Applied Mathematics Module to Promote Student Engagement Through Belonging

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Abstract

Student engagement has been shown to be impacted by a student's sense of belonging. As part of a wider initiative to enhance belonging amongst students on Mathematics, Physics and Engineering Foundation Year programmes, the Applied Mathematics team implemented a new assessment strategy using group-work and co-created industry contexts. The team co-created the industrial contexts with the whole student cohort, resulting in five industry themes. These themes were then used to develop five versions of a written test, with each version having questions contextualised to one of the five industry themes, and five versions of a group piece that each tackled a problem from one of these industries. Qualitative feedback from module evaluations suggested a positive impact on students. Additionally, the final exam, which was comparable with the previous year, saw an increase in attendance of 21% and increase in average attainment of 10%, suggesting a positive impact on student engagement within the module. However, this formed part of a wider initiative to promote student engagement through student belonging, and therefore these increases cannot be solely attributed to this assessment strategy.

Keywords: Student Engagement, Belonging, Co-creation, Employability, Group-Work, Assessment.

1. Introduction

Student belonging has been recognised as an integral part of the student experience, impacting student success, retention, and wellbeing (Thomas, 2016; Freeman et al., 2007, Skipper and Fay, 2023). Institutions have been encouraged to adopt strategies that foster a student's sense of belonging both outside and inside the classroom (UPP Foundation, 2021). This sense of belonging has been shown to correlate with student engagement (Webster, 2022; Gillen-O'Neel, 2021), with student engagement/dis-engagement being associated with attainment (Saqr et al.,2023).

Jackson, Capper and Blake (2022) argue that connection is fundamental to promoting this belonging; students who feel connected to their peers and their course are enabled to build support networks and develop confidence. Brown and Pawley (2024) find that students feel that community within a module or programme is the most important connection. One suggested mechanism to build connection is the use of groupwork and using employability themed groupwork has been shown to promote student engagement (Fairfax, 2022). Along with building connection, groupwork can build important skills for employability, even if students sometimes dislike this form of assessment (Francis, Allen and Thomas, 2022). A survey of employers by Quacquarelli Symonds (2022) found that the ability to work as a team was one of the top five most important skills employers are looking for in graduates.

Inclusion is key to developing a sense of belonging (Jackson, Capper and Blake, 2022), with students associating inclusive materials with a course's credibility and how well the course prepares them for the workplace. Co-creation has been shown to promote more inclusive practices (Mercer-Mapstone et al. 2017) with academics globally partnering with students to enhance the student experience (Reid et al., 2024). Bovill (2020) argues that whole class co-creation results in a more inclusive experience when compared with co-creation that only involves a smaller group of 'already-engaged' students. These engaged students often do not represent the breadth of experience and characteristics seen in the entire cohort. By using whole class co-creation, the views and opinions of a wider range of student backgrounds are taken into consideration. Blake, Capper and Jackson (2022) argue co-creation should become 'standard practice', with co-creation shown to be impactful in mathematics curricula (Morgiane and Brady – Van den Bos, 2024). This co-creation supports autonomy, another key factor in fostering a sense of belonging (Blake, Capper and Jackson, 2022).

In the 2023/24 academic year, staff teaching on Mathematics, Physics and Engineering integrated Foundation Year programmes at the University of Lincoln set out to enhance student engagement through initiatives to promote student belonging. The ~65 students enrolled on these programmes study a module entitled 'Applied Mathematics'. This module is designed to encourage students to use the learned mathematical content in context, preparing them for application throughout their programme. The students also study a second module in Mathematics, along with Physics or Chemistry and Study Skills. The Applied Mathematics team implemented a new assessment strategy to promote engagement through the use group work and embedded industrial contexts. The team used whole class co-creation to develop assessments that reflected the aspirations of the entire cohort. This approach aimed to promote inclusivity and student autonomy, which both foster a sense of belonging and thus enhance student engagement.

2. Student Co-creation Process

The students were introduced to the idea of a co-created assessment during one of the key lectures at the start of the year. The philosophy behind the co-created assessment was shared with them, with a particular reference to the desire to increase their sense of belonging and connection with the course. The students were surveyed to determine their career of interest, and these were collected into five different industries. Each student was issued with a post-it note on which they were invited to write down their first choice of career. The option to state 'unsure' was made available in order to avoid any pressure on those who were undecided. The students have several years of study ahead of them and this activity acts partially as a springboard to support them to begin to explore the careers that may be of interest to them.

The collected post-it notes were gathered into groups according to industry themes; these themes covered all the career paths that the students had stated. Since all the students were enrolled on Maths, Physics or Engineering programmes, the range of planned careers was limited, and this made it easier for the industry themes to be coordinated. These themes were:

- Aerospace Engineer.
- Astrophysics Lecturer.
- Biomedical Engineer.
- Mathematician.
- Renewable Energy Engineer.

In order to ensure that all students felt that they had been represented and to maintain the importance of inclusivity and belonging, the themes identified were shared with the students at the following lecture and they were invited to select which they felt best suited their career plan, again using post-it notes to gather responses. If a student felt that their preferred industry had not been included, then they had the opportunity to re-state their original choice.

If any students had not been happy with the options available then individual discussions would have been had with students to explain the options in more detail, and if necessary, provide additional test choice, however on this occasion the students were all happy with the options available and the industries listed above were used as a basis for the design of the assessments.

3. Assessment 1 – Industry based written test

The first assessment of the year, worth 30% of the module, included an online assessment followed immediately by a paper-based test, each equally weighted. The online section was as in previous years and assessed the underpinning mathematical skills through traditional questioning. The second part was written in five versions to incorporate each of the five co-created industries. Questions in this paper were contextualised and required more interpretation than the online section. Students were introduced to contextualised questions throughout the module in seminars, workshops and independent learning materials. The students were given the choice as to which one of the five papers they completed.

The five versions of the paper-based assessment included questions which related directly to the industry selected by the student. Each version contained questions with the same level of challenge and testing the same mathematical skills but with a context relevant to the industry of the title. By providing questions themed to the selected industry it was hoped that each student felt the content was relevant to their particular interest. The areas being assessed (probability, trigonometric functions and matrices) are all areas of mathematics that can easily be adapted to apply to a range of career paths and hence it was possible to find questions that were suitable for each of the options available to students. Three of the questions (out of six on each paper) were written to relate to the industry selected by the student. For example, the 'Aerospace Engineer' paper contained questions relating to detection of radar, orbit of a satellite (Figure 1) and drag forces acting on the wing of an aircraft, while the 'Renewable Energy Engineer' paper included questions that related to nuclear reactor accidents, wind turbines (Figure 2) and damage of electricity pylons.

Concerns about a potential lack of parity between the question papers were allayed by a thorough moderation process and analysis of the results of the papers after the students had completed the test. The analysis verified that the scores obtained by students were independent of their choice of paper.

In view of the length of time between the original invitation to select a career and the date of the assessment (the initial choices were presented at the beginning of the academic year in October, while the assessment did not take place until January) students were able to select an alternative assessment paper. This allowed for those who had altered their plans since the first choices were offered to update their selection.

The inclusion of the selected industries in the assessment was designed to reduce anxiety among students and to increase their sense of belonging. It was well received and appears to have succeeded in its goal. Students were advised in advance that they would be able to choose from one of five papers, and they appeared to enjoy making this selection on arrival; the reduction of the anxiety that they felt upon entering the room was visible. Feedback on the assessment was positive, with one student stating, *"I really enjoyed the industry-based exam … it was a really good way of experiencing what it would be like to problem solve in these industries"*.

5. A satellite's orbit traces an elliptical path around Earth.

The following pair of parametric equations model the path of the satellite:

$$x = \cos(t), \qquad y = \frac{9999}{10000}\sin(t)$$

where t is time after 12:00.

The coefficient of $\cos(t)$ is Earth's semi-major axis, the coefficient of $\sin(t)$ is Earth's semi minor axis.

Figure 1. Excerpt from the Aerospace Engineer question paper.

5. The blades of a wind turbine spin in a circular motion.

The following pair of parametric equations model the path made by the tip of one blade:

$$x = 52\cos(t), \qquad y = 52\sin(t)$$

where t is time after the blade starts spinning.

The coefficient of $\cos(t)$ and $\sin(t)$ is the length of the turbine blade.

Figure 2. Excerpt from the Renewable Energy Engineer question paper.

The workload in producing and moderating five different papers was significant for the three staff involved and should be a consideration for a team embarking on a similar project. Industries unfamiliar to the team required the most research to create authentic questions. The internal verification required in ensuring papers were of equal challenge was equivalent to the process that takes place to ensure assessments are of equal challenge between academic years. However, it was found that having established a process for producing these assessments the workload was reduced for the following year.

4. Assessment 2 – Desirable employer skills group work

The second assessment of the module, worth 10%, took place in April and was a live group work piece that assessed the students across the top five skills desired by employers, which were taken from the Quacquarelli Symonds 2022 report 'What do employer's want from today's graduates?' (2022, 9):

- Interpersonal Skills.
- Team Working.
- Problem Solving.
- Flexibility.
- Communication.

The students were asked to choose in advance one of the five available industry areas for this assessment, allowing them to select a different area from the previous assessment. They were then timetabled to the appropriate session. Sessions were deliberately timetabled in rooms that allowed the students to work in groups around a table, with space to move around and access to a whiteboard. In the lecture prior to the assessment students were provided with all the required information and most importantly advised that the assessment would begin at the moment they entered the assessment room; this was in order to model the environment experienced at an interview or meeting within an industrial context.

Upon arrival the students signed in and were allocated to a small group of four to six students. The students were purposely placed in groups with people outside of their friendship group and some time was allocated to networking which allowed the students to showcase their interpersonal skills. The students were observed during this time and were allocated a mark for interpersonal skills. Part of the aim of this was to encourage students to build connections with people on their course that they may not have interacted with previously. This provided an opportunity for students to make new connections and friends, which was particularly supportive for students who were still struggling to foster these relationships. Anecdotally, staff recognised students who had previously sat alone in lectures sitting with students from their problem-solving assessment group.

A short briefing outlined the session timetable and introduced the problem scenario. A different scenario was devised for each of the five industry areas which, briefly, were:

- Aerospace Engineer: You have been asked to design landing gear for a new aeroplane. This landing gear is under the wing and retractable. Mathematically model the movement of the landing gear.
- Astrophysics Lecturer: You need to run a session on the impact a passing meteorite would have on Earth's orbit. Calculate the distance between the Earth and the meteorite passing in a straight line.

- Renewable Energy Engineer: You are designing a robotic dog to replace humans to address maintenance situations in radioactive areas of a Nuclear Power Plant. Mathematically model the movement of the legs of the robotic dog.
- Biomedical Engineer: You have been asked to design a prosthetic arm. Mathematically model the position of the wrist as the arm moves.
- Mathematician: A Euler Brick is a cuboid where the length, width and height are all integers, and all face diagonals are also integers. Explore the properties that a Euler Brick must have.

It was made clear to the students that they were not expected to completely solve the problem, but that they should investigate how they would begin to tackle the problem in their small groups using the mathematical skills that they had acquired during the year and their employability skills. A variety of props were made available for their use if they wished, including paper and pen, balls, string, tape, boxes, stationery, whiteboards etc. and some students chose to use their laptops/devices. The assessment was open book, and students were invited to access any resources that they thought would support them in completing the task.

The students were observed to assess how well they interacted and worked as part of a team. Part way through the problem-solving phase a 'telephone call' was received which added new information to the scenario. This changed some aspect of the problem and was used to assess how flexible the students were; could they adapt to the required change?

After the allotted problem-solving time, the groups were given a short time to prepare and informally present their findings to the wider group, ensuring that every member had the opportunity to speak. Their communication skills were evaluated at this point. Once all the groups had presented, some feedback on the problem was provided and there was a brief discussion around the different approaches taken. After the students had left the room, their problem-solving skills were analysed by looking at the pages of working and/or models that they had produced.

The marking rubric was deliberately designed to be simple to use. A marking grid for each student that included the five skill areas was completed during and immediately after the assessment. Each marking point could be awarded 0 – 'does not meet standard', 1 – 'sufficiently meets standard', 2 – 'exceeds standard'. This method was chosen as it reflects the shortlisting practice for hiring at our institution, again linking the assessment to industry. The simplicity of the marking rubric meant that the marks were finalised shortly after each of the sessions.

This assessment was enjoyable and was well-received by the students and staff involved. Whilst some students seemed a little nervous when they first entered the room, the students relaxed for the most part and were smiling and laughing during the assessment, particularly when the fake 'phone call' altering the scenario came through. The team were conscious of students with support plans however, no adjustments were required in this iteration owing to the inclusive nature of the assessment. In future iterations, if any support plans require adjustments to the assessment the team will respond to any support requirements accordingly.

Students commented on how much they had enjoyed the session, and that it had been the best assessment they had ever done. One example comment *"[the best thing about this module was] the student-led assessments at the end of the year, giving us a chance to work together on industry related problems"*.

5. Conclusion

The Applied Mathematics team set out to use co-creation and industrial contexts to design, develop and implement an assessment strategy that fostered a sense of belonging amongst students. This formed part of a wider strategy to develop belonging in students on Mathematics, Physics and Engineering Foundation Year programmes with the ultimate aim of improving student engagement. Student feedback for this module suggested the initiative had a positive impact on the student cohort, with practitioners observing benefits to student engagement with both the module content and with their peers. Attendance at the final exam (a comparable assessment to academic year 2022/23) increased from 77% to 98% suggesting an increase in student engagement. Additionally, average attainment increased by 10%, suggesting students also saw impact on their learning. It should again be noted that this assessment strategy formed part of a wider initiative, so these results cannot be solely attributed to this innovation. A formal study is being considered for a future iteration however, this paper outlines a case study of how initiatives implemented to aid student belonging can support students to engage and attain.

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RESEARCH ARTICLE

Making Mathematicians: Developing expert attitudes with authentic maths activities.

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Abstract

One of the goals of an undergraduate degree in mathematics is to transform students' perceptions of mathematics from calculations with the rote application of formula to the reflective, creative problem-solving that is highly valued in academia and other professions. This can be achieved by incorporating authentic mathematical activities (i.e. the kind of tasks a maths graduate can expect in the workplace) into the design and delivery of undergraduate programmes. The Middlesex maths team have implemented a variety of novel teaching and learning methods into their specialist maths provision to achieve this aim. Our approach includes the use of generative artificial intelligence; extended, vague, problem-solving assignments; student choice in assessment; and reflective components. In this paper we discuss the implementation, benefits, and challenges of these authentic mathematical activities, focusing on their effect on students' perceptions of mathematics during their studies. We use questionnaires to determine how students' perceptions of mathematics change while doing these activities and their attitudes to the activities themselves.

Keywords: Authentic assessment, attitudes, perceptions, identity, Mathematics Attitudes and Perceptions Survey, problem-solving, choice in assessment, artificial intelligence, reflection.

1. Introduction

Authentic assessment in higher education can be characterised as "assessment requiring students to use the same competencies, or combinations of knowledge, skills and attitudes that they need to apply… in professional life" (Gulikers, Bastiaens and Kirschner, 2004) and is a significant shift from traditional exam-based assessment, which is itself highly dissimilar to professional practice. In a systematic review Villarroel et al. (2018) conclude that authentic assessment has a positive impact on a variety of abilities related to employability, such as autonomy, motivation and self-regulation. Further, the authors distil authenticity into three dimensions: realism, cognitive challenge and evaluative judgement, and provide a framework for designing and operating authenticity assessment in higher education programmes.

In professional life, mathematics graduates have a reputation for analytical thinking and problem-solving that are particularly "sought after by employers" (QAA, 2023). One goal of authentic assessment in mathematics, therefore, is to ensure students explicitly develop these skills as part of their mathematics undergraduate experience, which requires more from them than simply being able to perform well in controlled exam conditions.

Authentic assessment has been a characteristic of Middlesex University mathematics degrees, with reflection, communication and problem-solving activities included in the degree programme when it relaunched in 2014 (Megeney 2016). The learning and teaching strategy for these programmes has been continually developed: all exams (high-stakes, controlled environment, end-of-module summative assessment) were removed in September 2021 (although some mid-module, low-stakes in-class tests remain) in favour of authentic assessment, which attempts to emulate the specialist work that mathematics graduates will perform in their professional roles. In Masterson et al. (2024) we distinguish between "authentic assessment", whose outputs have professional analogues (such as reports, computer code, or presentations) and "authentic problems" whose inputs are typical of professional environments (for example vague, imprecise, or requiring a significant element of judgement to begin).

In this paper, we examine the effects of authentic assessment on student attitudes and perceptions of mathematics. The premise is that if students are persistent and confident in mathematics, believe in its applicability to the real world, and are learning to develop understanding rather than just for completing tasks then they have expert-aligned attitudes that they can apply in professional life. We examine this relationship by deploying the Mathematical Attitudes and Perceptions Survey (MAPS) on undergraduate mathematics students whose degree programmes contain many authentic activities.

In the next section we describe four categories of authentic activity (*Problem-solving, Artificial intelligence, Reflection, and Choice in assessment*) that are features of the Middlesex university undergraduate degree programmes (two further categories, *Communication* and *Outreach* are described in Jones et al. 2025). First, we introduce the MAPS survey tool.

1.1. The Mathematics Attitudes and Perceptions Survey

The Mathematics Attitudes and Perceptions Survey (MAPS) was developed by Code et al. (2016) to characterise undergraduate student perceptions of mathematics in educational settings. The survey consists of 32 statements which students respond to with a 5-point Likert scale (from "Strongly Disagree" to "Strongly Agree"). It contains seven subscales: *Confidence* (the perceived ability to successfully engage in mathematical tasks), *Growth mindset* (the belief that mathematical ability can be developed rather than an innate property), *Real world* (the view on the applicability of mathematics to everyday life), *Persistence* (the attitudes and approach when getting "stuck" on a problem), "Interest" (the motivation in studying mathematics), *Sense making* (learning mathematics for understanding, rather than for completing tasks), and *Answers* (on what form solutions to mathematical problems can take). The authors performed a factor analysis on a pool of specialist and non-specialist maths students in North American universities ($N = 3411$). The whole instrument achieved a Cronbach's alpha of 0.87 (95% confidence interval $[0.86, 0.88]$). An expert consensus, determined from a panel of mathematics faculty at British Columbia University ($N = 36$), was obtained for 29 of the MAPS statements. The MAPS instrument therefore quantifies the extent to which undergraduates' attitudes and perceptions of mathematics agrees with that of experts.

In their initial study Code et al. (2016) found that students' attitudes varied across courses, with first-year Calculus 1 courses having students with lower MAPS scores (i.e. attitudes towards mathematics less aligned with those of experts) compared with students on a second-year Introduction to Proof course. They also reported a generally positive correlation between student grades and their MAPS scores. A further study by Maciejewski et al. (2021) demonstrated lower

MAPS scores for first-year students taking “development” maths courses (required, but non-credit bearing, courses for students entering university with low mathematics attainment) compared with first-year students taking “college-level” maths courses for credit.

Of interest to the present work, Code at al. (2016) also examined students who completed the survey in both the September and April of their first academic year, reporting “All MAPS categories… saw declines over the academic year”, which is to say that students’ attitudes to mathematics moved further away from those of expert mathematicians during their first year at university. Further, this decline was present even for courses using “flipped” instructional methods (although the decline in the *Real world*, *Persistence*, *Sense making* and *Answers* categories weren’t statistically significant). The authors speculate that this is partially due to first-year courses’ emphasis on “solving low-level inauthentic problems”. A similar first-year decline in expert-aligned attitudes towards physics (using a related survey) is reported in Cahill et al. (2014).

In contrast, Ozimek et al. (2024) report that amongst prelicensure nursing students, those undertaking a first-year Clinical Maths module designed with “problem solving in authentic situations” have greater MAPS scores compared with those who have yet to take the course. These results suggest that authenticity is an important element of maths courses that aim to develop students into expert mathematicians.

2. Authentic activities

2.1. Problem-solving

The QAA (2023) recognise “the fundamental nature of MSOR as a problem-based subject area” and emphasise that graduates should have skills “in the solution of new problems arising in professional work or in further study”. Problem solving ability has traditionally been assessed in the second half of exam papers through applications of familiar theory to previously unseen, but perhaps not entirely unfamiliar problems. In our view this kind of problem solving is inauthentic for two reasons: first, mathematics professionals are more likely to identify or develop appropriate theory in response to specific problems, rather than look for applications of a particular theory. Second, problem solving in the professional domain involves a wide range of skills such as research, experimentation, collaboration and communication that cannot be assessed in controlled exam conditions.

Since its inception, the Middlesex mathematics degree has included a core level 5 module (Year 2 of an undergraduate degree in the UK), dedicated to developing the desirable problem-solving skills mentioned above (Jones and Megeney 2019, and Masterson et al. 2023). Following revalidation in 2022, the module increasingly emphasises the “mathematization” (see Freudenthal 1968) of vague and imprecise problems rather than solving a problem already expressed mathematically. For example, the (space-themed) 2023-24 assessment consisted of 8 possible problems, including

1. A solar powered satellite is on an elliptical orbit of the sun. Explore how much energy the satellite can generated per orbit and per hour. What capacity batteries should the satellite carry?
2. Suppose an object is moving around randomly in space. Will it ever reach Earth?
3. Celestial bodies tend to be approximately spherical. Can we measure how spherical they are in order to compare them?

Small groups of students chose a problem to work on over an eight-week period with the brief that they are “primarily being assessed on the approach [they] take to solving problems, rather than the actual solution.” Indeed, only 10% of marks were allocated for the “solution” of the problem, with the more marks available for an account of the "problem solving" process (10% for an introduction, mathematical formulation and strategy, and 30% for a thorough description of the problem-solving process, including which activities did and did not help the group make progress, together with an account of how the group interacted). At the start of the module, students learn problem-solving approaches such as Polya (1990), Mason et al. (2010) and Bransford and Stein (1993) to develop their problem-solving skills and give them the language and choice of frameworks to express and reflect on their process (Jones and Megeney, 2019 and Masterson et al., 2023).

Vague, open-ended problem solving has also been incorporated into other modules such as level 5 *Mathematical Statistics*, where students have an unconstrained choice of dataset to analyse and must identify an interesting question, choose an appropriate analysis to perform, and are given agency in demonstrating they have satisfied the learning objectives (Masterson et al. 2024).

2.2. Artificial intelligence

In November 2022 ubiquitous access to generative artificial intelligence began with the release of ChatGPT-3.5 by OpenAI. Universities recognised risks in this technology, particularly concerning ethical use, equality of access, and academic integrity but also opportunities in transforming learning experiences and increasing graduates' employability and productivity through AI literacy (Russell Group, 2023). Responses have been mixed, with some courses returning to the pre-covid practice of controlled assessment conditions (such as exams), while others explicitly include the use of generative AI as an option or requirement in assessment.

Whether AI can generate novel mathematical research remains to be seen. However, eminent researchers have recognised that potentially "it may only take one or two further iterations [for] the tool being of significant use in research level tasks" (Tao, 2024). It is important, therefore, for students to experience using generative AI tools in order to understand the capabilities, limitations, and appropriate uses of this technology for mathematical activities. In any case, following the reported productivity gains of using large language models for workplace tasks (Dell'Acqua et al. 2023), universities should prepare students for careers in which these technologies are widely used for knowledge work and decision-making. The think-tank Demos suggests that the challenge for universities in this setting is to "equip their graduates with skills, competencies and dispositions that will enable them to offer something different in the workplace" (Demos, 2023).

In response, the Middlesex mathematics team have begun including generative AI into the syllabus and assessment of their mathematics programmes. The aim is that as students develop their mathematical and statistical knowledge they also develop the AI literacy to be judicious in its use, critical of its output and are able to articulate the value of their knowledge and skills in comparison to a naïve user of generative AI.

In assessment for the level 5 *Mathematical Statistics* module, students first complete some data analysis questions then write a reflective report comparing their solutions to attempts made by a large language model (Masterson et al. 2024). In the final piece of assessment students will be invited to incorporate generative AI into their data analysis directly, but explicitly.

Students are also permitted to use generative AI to support their extended written communication tasks in the level 5 module *Problem-Solving and Communication*. These briefs are centred on experiences that the students have had such as museum trips or guest lectures (Jones et al. 2025), and students are strongly encouraged to personalise their work and write from their own perspectives. Consequently, although students might use generative AI to help structure or redraft work, the content and the judgement of what to include, will be their own.

In the *Problem-Solving and Communication* syllabus, generative AI is also used to support students in producing high-quality mathematical animations using the manim library (see, for example, Sanderson 2024). Writing manim code requires a non-trivial understanding of object-oriented Python, which ordinarily has a significant learning curve. However, after a single two-hour workshop using generative AI to write manim code, students were able to produce high-quality animations of their own design, which they could optionally use as part of an assessment.

2.3. Reflection

Villarroel et al. (2018) identify evaluative judgement as an important dimension of authentic assessment. The aim is for students to "develop criteria and standards about what a good performance means" ultimately endowing the student with "the lifelong capacity to assess and regulate their learning and performance", which will enhance their employability.

At Middlesex university, evaluative judgement is developed in reflection activities that are embedded throughout the mathematics programmes. In the level 4 (Year 1 of an undergraduate degree in the UK) module *Data and Information*, students reflect on their participation in outreach activities (such as SMASHfest see Griffiths and Keith 2021, Jones et al. 2025 and Megeney 2016). These reflections focus primarily on their experience of interacting with staff, fellow students and the public, and how these experiences may benefit their mathematics education.

At level 5 (Year 2 of an undergraduate degree in the UK), the module *Problem-Solving and Communication* is assessed through group problem-solving (discussed in Section 2.1) and a portfolio of communication briefs (Jones et al. 2025). Students also submit a written reflection on their assessment (worth 15% of their overall grade) that requires them to comment on their group dynamics, evidence their improvement as problem-solvers, and critically evaluate both their submitted communication briefs and the process they followed to produce them. At this level, students are given a structured set of prompts to support a high-quality reflection. Students are asked to consider the knowledge and skills (including time management) that they have used; to identify particular challenges; to justify their approach; to explain how they engaged with formative feedback; and describe what could be improved or would be done differently in the future. These reflective questions have natural synergies with problem-solving assessment as Polya's (1990) fourth step is "looking back", where students focus on checking the result and argument, and seeing if the result can be derived differently, or is now immediately clear from the student's new point of view.

At level 6 (Final year of an undergraduate degree in the UK), reflective tasks are present but are less explicitly structured so that students can take ownership of this process. The *Project* module, for example, requires students to keep a reflective diary of meetings with their supervisor, but only gives minimal guidance on the contents. The module *Real and Complex Analysis* builds on the students' reflective ability by including evaluative judgements of their peer's work.

2.4. Choice in assessment

Student engagement in learning can be improved by granting a degree of agency over their assessment as "flexibility in assessment allows students to take a proactive role in their learning" (Pretorius, van Mourik and Barratt, 2017). The Middlesex maths team have incorporated student choice into assessment in two distinct ways: first, we allow students to select the format of their submission, which could be written, drawn, audio recorded, or video recorded, or a combination of these formats for an individual piece of coursework. This choice of format was present in the level 5 *Problem-Solving and Communication* module, as well as more mathematically technical modules such as the level 6 *Real and Complex Analysis* where, for example, students choose the format of their proof that multivariable polynomials are differentiable.

Student choice of assessment format is facilitated in part by the three-year loan of iPads to all undergraduate maths students (Jones, Megeney and Sharples 2022), which provides a common, equitable platform for multi-media submissions. Students may wish to choose the format that they believe best demonstrates their mathematical ability or take the opportunity to develop their skill and confidence in other formats. Including this wide choice made the assessment more accessible, reducing the need for reasonable adjustments and improving the inclusivity of the modules.

Second, in many module assessments students have a substantive choice over the question they answer (Masterson et al. 2024). This includes a free choice of dataset and method of analysis in the level 5 *Mathematical Statistics* module (with some guidance on the learning outcomes expected to be demonstrated, such as the calculation and interpretation of confidence intervals), and a choice of vague problem for group work in level 5 *Problem-Solving and Communication* (see Section 2.1).

These significant choices in assessment require students to have a good overview of the subject and to be able to make sound judgements on their overall approach to a task, which are desirable features for graduate mathematicians. However, there is a risk that students make unsuitable choices, for example on a topic that is particularly challenging to communicate in an audio-only format, such as geometry, or a dataset that isn't suited to the learning outcomes, for example categorical data for the calculation of confidence intervals. However, formative submissions, and frequent check-ins serve as opportunities to guide students' judgement and reinforce their learning to correct any such errors before summative submission.

3. Methodology

We conducted an anonymous survey between July and August of 2024 of current students and recent graduates of our undergraduate mathematics programmes BSc Mathematics, BSc Mathematics with Computing, and BSc Mathematics and Data Science. The survey was adapted from the MAPS in the following way: for brevity the three statements in the *Interest* subcategory and the two uncategorised statements were removed. Our rationale for this decision was that the MAPS was designed for undergraduates taking general maths modules, whereas students who had chosen to study specialist mathematics degrees had an established interest in mathematics. We also introduced the statement "I am a mathematician" to explore students' feelings of mathematical identity, giving a total of 28 statements.

In the survey, participants were first asked to recall how they felt about mathematics before joining Middlesex University and record their recollection through rating their agreement with the MAPS and identity statements. Next, for each of the six learning and teaching elements *Problem-solving, Artificial intelligence, Reflection, Choice in assessment, Communication, and Outreach* participants were asked whether they'd encountered this element: an affirmative response gave four additional statements "[element] made me more confident in mathematics", "[element] increased my anxiety", "[element] helped me prepare for my professional career" and "[element] is an important part of mathematics", and a free-text response about their experience of this element. Finally, participants were given the MAPS and identity statements a second time to rate how they currently felt. The survey and research methodology were approved by the Middlesex University ethics committee ref: 28902.

Participants rated each statement on the scale *Strongly disagree, Disagree, Neither agree nor disagree, Agree,* and *Strongly agree*. Our analysis differs from that of Code et al. (2016) who dichotomise responses into scoring one point if the direction of the participants response (agree or disagree) matches that of the expert consensus, and zero points otherwise. This gives an easily interpretable "consensuality" measure similar to the common positivity measure used for Likert data (Jeong and Lee, 2016), which is statistically robust as it models agreement with each statement as a Bernoulli random variable.

Instead, to also capture the strength of agreement, we score from -2 (Strongly disagree) to 2 (Strongly agree) before multiplying by -1 if necessary to align the scale with the direction of the expert consensus for that statement. We then calculate an average score for each participant, question category and time. This "intervalist" analysis of Likert data is regarded as statistically robust (Carifio and Perla, 2008, Norman 2010, Sullivan and Artino, 2013) although there has been substantial debate about the appropriate analysis of attitude survey data since Likert (1932) introduced his eponymous methodology. An advantage of the approach taken here is that small changes in response (for example from *Agree* to *Strongly agree*, or from *Neither agree nor disagree* to *Disagree*) are captured in the average scores. We report summary statistics across these averages in the next section.

The non-MAPS statement "I am a mathematician" and the statements about the six specific teaching and learning elements do not have an established expert consensus, so are simply scored from -2 (*Strongly disagree*) to 2 (*Strong agree*), with the exception of "[element] increased my anxiety" for which this scale is reversed. Consequently, we report data so that positive scores for MAPS statements indicate alignment with the expert consensus, and positive scores for other statements have a positive connotation (more confidence, less anxiety, etc.).

As the survey was administered at a single time point our methodology isn't a true pre/post study to measure change in attitudes, which is a limitation of the design. Participants may be biased in their recollection of pre-university attitudes, perhaps by judging prior attitudes more harshly in light of their current mathematical experience. Our "quasi-pre/post" design, however, does capture the extent to which participants currently perceive how their attitudes have changed since before joining university.

Data analysis was performed in the R programming language and the code is available in Sharples (2025). In this paper we report on the MAPS and identity statements, and participant perceptions about *Problem-solving, Artificial intelligence, Reflection,* and *Choice in assessment*. For discussion and results on the *Communication* and *Outreach* activities see Jones et al. (2025).

4. Results

A total of $N = 13$ surveys were completed. Participants reported having joined the university between 2014 and 2021 so cover a wide range of the Middlesex mathematics provision. We also include the results from an additional participant who completed only the first half of the survey. All other surveys were fully completed apart from one missing response for question 6 at the "before university" time point.

4.1. MAPS and identity

Overall results are summarised in Table 1: we see that, on average, participants' attitudes before joining university to study a specialist mathematics undergraduate degree mildly align with the expert consensus (mean score of 0.554), but there is an improvement in their attitudes after completing at least some undergraduate study (mean score of 0.899). Further, before university the least expert-like participant disagreed with the expert consensus overall (mean score of -0.24), but after some undergraduate study all students agreed with the consensus overall (minimum mean score of 0.423).

There was a substantial shift in the attitudes about mathematical identity. Recollecting their attitudes before joining an undergraduate mathematics degree, of the 14 participants 6 agreed and 4 strongly agreed with the statement that they were mathematicians. At the time of the survey this improved to 5 agreeing and 8 strongly agreeing out of 13 respondents. The average Likert scores can be seen in Table 1.

Table 1: Likert scores comparing the recollection of attitudes before university (pre) and attitudes at the time of completing the survey (post). Minimum and maximum are taken across the average scores for each participant.

Questions	Time	n	Mean Likert score	sd	Min	Max
MAPS subset	pre	14	0.554	0.443	-0.24	1.08
MAPS subset	post	13	0.899	0.375	0.423	1.69
Identity	pre	14	0.857	1.03	-1	2
Identity	post	13	1.62	0.506	1	2

Results for individual question categories can be seen in Figure 1. For each category there was a closer alignment of attitudes to the expert consensus following some undergraduate study, particularly in the *Persistence* (+0.49), *Confidence* (+0.47), and *Answers* (+0.43) categories.

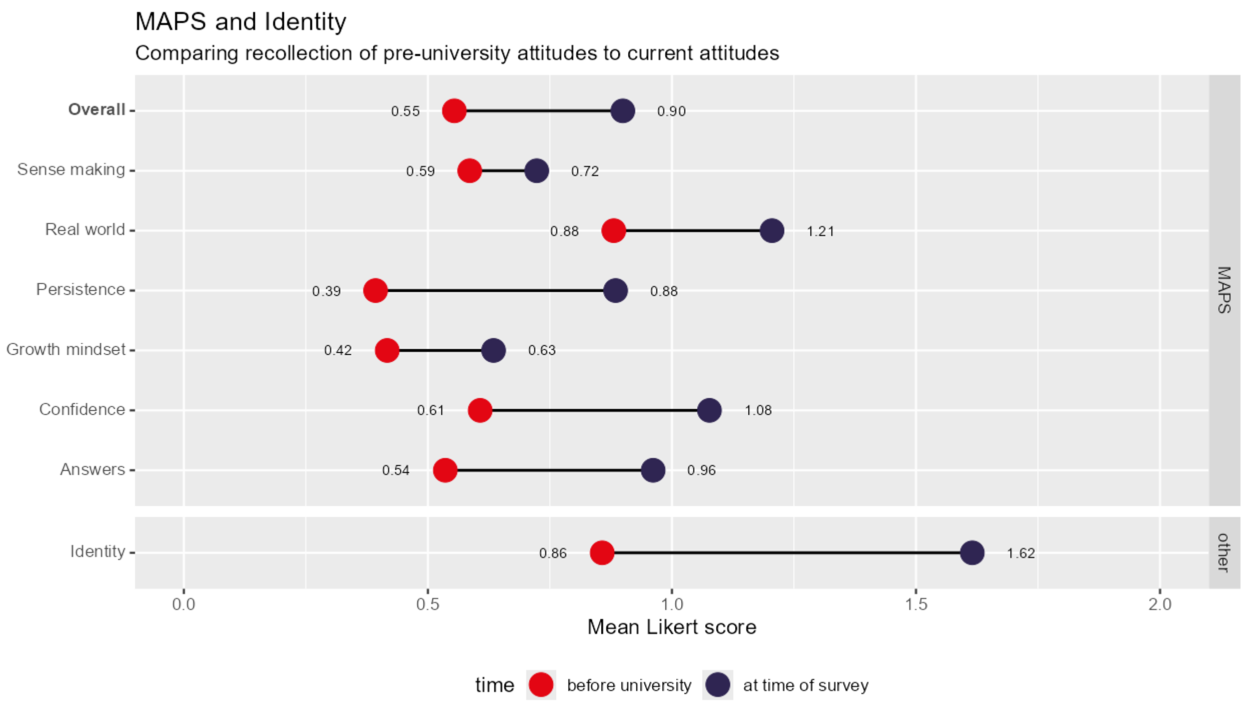

Figure 1: Comparison of students' attitudes aggregated by MAPS category (positive scores show agreement with the expert consensus) with an additional question on mathematical identity.

4.2. Attitudes to teaching and learning elements

In general, respondents had positive attitudes about the use of *Artificial intelligence, Choice in assessment, Problem-solving,* and *Reflection* in their degree programmes (see Table 2). There was substantial agreement that all these teaching elements improved respondent confidence, and that they are important to mathematics. Further, respondents substantially agreed that *Problem-solving* helped prepare them for careers, but felt less strongly that the other teaching elements supported this outcome. Respondents agreed that *Problem-solving* and *Choice in assessment* didn't increase anxiety, but were more ambivalent about anxiety from the *Artificial intelligence* and *Reflection* elements.

Table 2: Likert scores of respondent attitudes to selected teaching and learning elements.

Element	Statement	n	Mean Likert score	sd
Artificial intelligence	Improved confidence	4	1.25	0.5
Artificial intelligence	Important to mathematics	4	1.75	0.5
Artificial intelligence	Career preparation	4	0.75	1.26
Artificial intelligence	(didn't) increase anxiety.	4	0.25	1.5
Choice in assessment	Improved confidence	14	1.29	0.73
Choice in assessment	Important to mathematics	14	1.21	0.70
Choice in assessment	Career preparation	14	0.50	1.09
Choice in assessment	(didn't) increase anxiety.	14	1.29	0.61
Problem-solving	Improved confidence	14	1.71	0.47
Problem-solving	Important to mathematics	14	1.86	0.36
Problem-solving	Career preparation	14	1.5	0.85
Problem-solving	(didn't) increase anxiety.	14	1.21	0.89
Reflection	Improved confidence	11	1.45	0.52
Reflection	Important to mathematics	11	1.18	1.17
Reflection	Career preparation	11	0.91	1.04
Reflection	(didn't) increase anxiety.	11	0.64	1.36

Looking at the individual responses in Figure 2, we note that attitudes to *Problem*-solving were generally positive, while attitudes to *Choice in assessment* were mainly positive and neutral, whereas both *Artificial intelligence* and *Reflection* polarised respondents. In particular, some students stated that the use of *Artificial intelligence* and *Reflection* increased their anxiety and that *Reflection, Choice in assessment*, and *Artificial intelligence* didn't help prepare them for their careers.

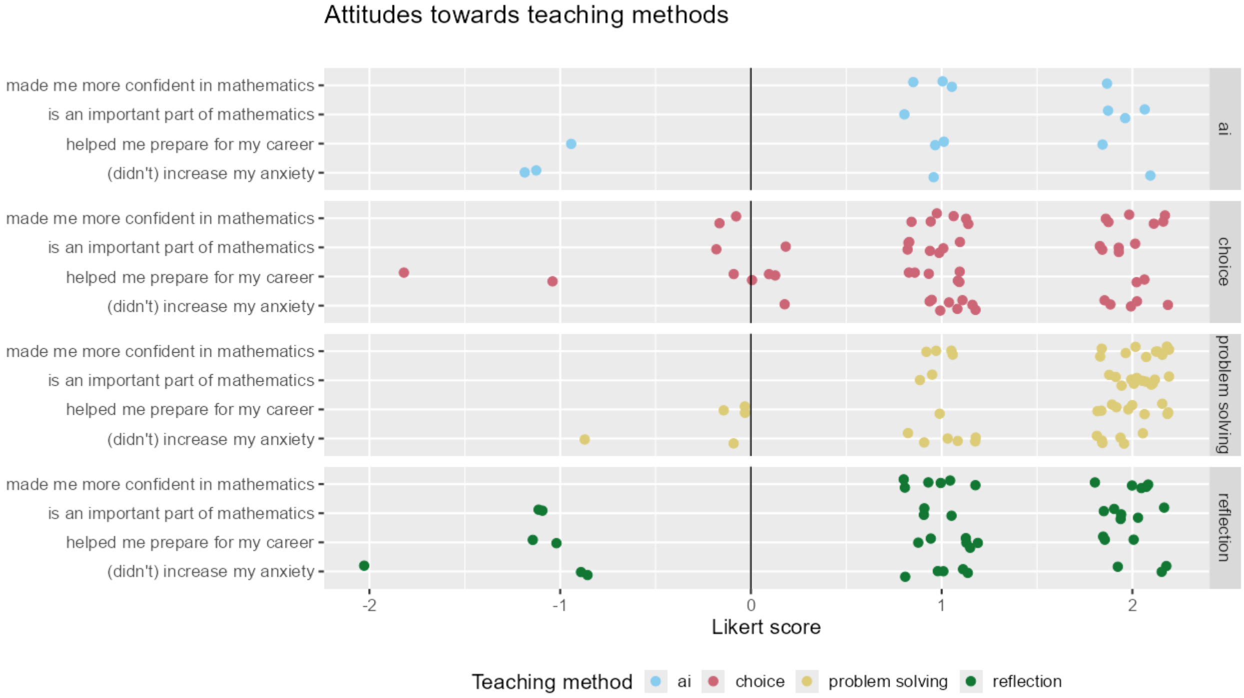

Figure 2: Comparison of attitudes to selected teaching and learning elements. Each point represents an individual respondent's Likert rating. Points are jittered to prevent overplotting.

Respondents who left free text comments were positive about the teaching elements. They reported benefits to individual approaches to learning as *Choice in assessment* "allowed me to properly understand my capabilities and plan my studying accordingly" and "is helpful as we all have different ways of learning and interests".

Benefits to learning outcomes were also reported as *Problem-solving* "requires time and development [but]… leads to students thinking independently" and "allowed me to think more outside of the box when it came to answering questions", while *Choice in assessment* "helps [in learning] more about a specific approach to a problem" and *Reflection* "is an important part of mathematics learning… [that leads to] improvement in the area [reflected upon]".

Further, the free text comments were used to express appreciation with respondents "grateful to have had" *Choice in assessment* and reporting that they "Loved the problem-solving module!". Respondents also gave suggestions for future developments reporting that *Choice in assessment* would "give students more flexibility and time management" and that *Artificial intelligence* "should be explored and used by future undergraduate students and lecturers… [It] can revolutionize the education of mathematics".

5. Discussion and future work

The Middlesex university mathematics degree programmes have been designed with authentic activities embedded throughout, to develop graduate skills and therefore employability in students (Megeney 2016). Students on these programmes report that their attitudes to mathematics have substantially shifted towards those of experts, compared to the recollection of their pre-university attitudes. Although we didn't take an objective measure of the student's attitudes at the start of their course, at least at the time of the survey the students believed that they had become more expert-like in their attitudes.

It is plausible that the inclusion of authentic activities is at least partially responsible for the expert-alignment of students' attitudes for two reasons: first, the students themselves generally report that these activities improved their confidence, helped them prepare for their careers, and are important parts of mathematics. Second, other studies using the MAPS show attitudes becoming *less* expert-like in both traditional and flipped classroom mathematics courses with assessment "depending largely on traditional written exams in all cases" (Code et al., 2016). This is perhaps suggestive that inauthentic exams have a detrimental effect on student's mathematics attitudes, which is in line with the known negative effects of exams in higher education in general (French, Dickerson and Mulder, 2023).

A larger scale study, with pre and post MAPS measures, across multiple universities with differing maths provisions would be necessary to robustly establish if the inclusion of authentic activities such as those described above has a significant effect on student attitudes. However, the impact of this work is potentially very high as these attitudes include those that employers recognise as being particularly sought after in graduates.

Generative AI activities are a recent inclusion in the programmes, which accounts for the lower number of respondents ($n = 4$). It's clear that some students are anxious about its use and don't feel that the inclusion of AI activities (at least in their current form) have helped prepare them for their careers, so the risks and affordances of this technology in mathematics programmes will need to be carefully considered. However, there is significant potential in graduate skill development, as illustrated in the manim example discussed in Section 2.2: here generative AI can support mathematics graduates in education and communication roles to produce high-quality materials without the need for extensive, specific technical training that is otherwise beyond the scope of their curriculum. Including some examples of the appropriate use of generative AI in course design has the potential to produce technological agile graduates who can rapidly learn new skills.

A small number of respondents seemed to have a negative view of the reflective activities. Villarroel et al. (2018) argue that "students need to be exposed to a variety of [formative] tasks with diverse performance requirements" to develop evaluative judgement, which is perhaps in tension with giving students choice in assessment. Some students, perhaps those with less confidence, may choose a smaller range of familiar assessment formats and question types, giving themselves less opportunity to develop judgement through reflection. A whole programme approach could therefore be necessary to ensure that for any given assessment students have agency, but also experience a variety of tasks and performance requirements across their whole programme.

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CASE STUDY

Generating maths solutions with ChatGPT

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Abstract

Creating step-by-step maths solutions takes significant time and effort. Starting with a ChatGPT-generated draft and proceeding to carefully review and improve it can lead to significant time savings. In this case study, solution documents were created for two past exam papers in a second-year undergraduate maths module. Using a ChatGPT-generated draft as a starting point led to a total creation time of 2 hours and 36 minutes, compared to 4 hours and 31 minutes without the assistance of ChatGPT. This article explains the procedure for obtaining the ChatGPT draft, provides the background for the study, and presents the findings. It highlights key strengths of using ChatGPT for this purpose, including its speed, accuracy and quality of explanation. Limitations are also discussed, such as the risk of calculation errors, incorrect workings or over complicated answers.

Keywords: Generative AI, ChatGPT, Maths solutions, Time efficiency

1. Introduction

The growing popularity of generative AI models like ChatGPT has forced educators to reconsider various aspects of maths teaching. These models offer potential educational benefits such as personalised and adaptive instructional support (Ahmad, Murugesan and Kshetri, 2023). ChatGPT also has the potential to help students overcome learning barriers and strengthen their ability to transfer knowledge into new contexts (Mollick and Mollick, 2022).

However, caution is necessary as generative AI becomes increasingly prominent in classrooms. Bastani, et al. (2024) investigated if students given access to a ChatGPT-4 based tutor during study sessions performed better than those who weren't. Access to the tutor increased study performance by 48%, but decreased performance by 17% in a subsequent exam when tutor access was unavailable. The authors suggest that students may become overly reliant on the tutor during practice, preventing them from effectively learning key problem-solving skills.

The problem-solving abilities of generative AI models are advancing rapidly, with significant improvements observed between ChatGPT-3.5 (released in November 2022) and ChatGPT-4 (released in March 2023). Newton and Xiromeriti (2023) conducted a scoping review on ChatGPT's performance in multiple-choice questions across various subject areas. Out of 18,862 tested questions, ChatGPT-3.5 answered 49.5% correctly, significantly lower than ChatGPT-4's 75.5% accuracy rate. To assess advancements in mathematical reasoning ability, Frieder, et al. (2024) tested ChatGPT models on a novel dataset featuring exercises from graduate-level textbooks on probability theory, topology and functional analysis, as well as holes-in-proofs exercises and symbolic integration tasks. Despite performing below the level of an average graduate student, ChatGPT-4 significantly outperformed older versions of ChatGPT. Newer models are showing continuous improvements in advanced reasoning, with ChatGPT-o1 (released in December 2024) scoring 83% on the American Invitational Mathematics Exam, a qualifying exam used in the selection process for the US Maths Olympiad team (OpenAI, 2024).

ChatGPT's responses are mostly correct, with newer models making fewer and fewer mistakes. However, it has yet to achieve perfection - and likely never will. Alkaissi and McFarlane (2023) found that ChatGPT fabricated references, remarking, "*While ChatGPT can write credible scientific essays, the data it generates is a mix of true and completely fabricated ones.*" Giray (2024) calls on academics to carefully verify AI-generated content and develop a deep understanding of the limitations and risks of AI tools.

Other large language models have also made significant progress in problem-solving over the past few years. Claude 3 Opus (released in March 2024) outperformed its main competitors across a range of mathematical domains, including grade school math, undergraduate knowledge, and graduate-level reasoning (Anthropic, 2024). AlphaGeometry2, a specialised model developed by Google DeepMind, recently outperformed gold medal standards in Math Olympiad geometry (Chervonyi, 2025).

This case study, conducted in summer 2024, explores the efforts of a lecturer in an engineering maths module to develop solution documents for two past exam papers. For the first exam paper, ChatGPT-4o (released in May 2024) generated draft solutions, which the lecturer then verified, corrected, and refined. For the second exam paper, solutions were created without the assistance of generative AI. ChatGPT was selected based on the lecturer's personal preference, though other large language models like Claude or Gemini would have been equally suitable for this task. This article provides background details on the maths module in question, details the input and output methods used to generate the draft, presents the case study findings, and analyses ChatGPT's strengths and limitations for this application.

2. Background

Exam solution documents were created for a second-year undergraduate engineering maths module at Munster Technological University. The exam paper was a two-hour closed book written assessment with four questions covering vectors, matrices, differentiation and integration. The module introduced fundamental concepts in each of these areas, including:

- Addition, subtraction and scalar multiplication of vectors;
- The dot product and cross product for vectors;
- Addition, subtraction and multiplication of matrices;
- Finding the determinant of a matrix;
- The inverse matrix method for solving matrix equations;
- Parametric differentiation, implicit differentiation and partial derivatives;
- Integration by substitution, integration by parts and integration with partial fractions.

3. Generating draft solutions with ChatGPT

This section outlines the input method, output method and prompt design used to obtain draft solutions from ChatGPT.

3.1 Input Method

In subjects such as English and business, text-based prompts are well suited since questions can easily be typed using a standard keyboard. However, entering maths questions in plain text is challenging due to mathematical notation such as fractions and integral signs. One option is to type prompts using LaTeX syntax, which ChatGPT can accurately interpret. However, this approach is time-consuming and prone to errors. If a handwritten or digital copy of the question is available, a more efficient approach is to upload an image or screenshot. ChatGPT-4o supports image uploads and is effective at interpreting the mathematical content within them. If a PDF file containing multiple questions is available, it can be uploaded directly. This method was used to create the draft solutions in this case study.

3.2 Output Method

ChatGPT's default behaviour is to provide answers in a chat-based format, with mathematical expressions embedded directly in the conversation where necessary. As the chat history grows, it can become difficult to navigate. While useful for quickly reviewing responses, this format is not ideal for sharing or editing the output. Taking screenshots is useful for capturing a key section of the chat, but this method lacks the flexibility needed for editing responses. In this case study, ChatGPT was prompted to output its responses in the form of LaTeX code. The response was copied into a LaTeX editor, reviewed for correctness, and modified as needed. The final version was exported as a PDF to facilitate efficient sharing and distribution.

3.3 Prompt Design

In addition to uploading the PDF of the exam paper, a written prompt was given to ChatGPT to guide its response. It took three iterations of prompt refinement to obtain a satisfactory result; however, it is worth noting that the prompt could still be improved further. The first prompt attempted was: "Provide written solutions to the given exam paper. Present your answer in a latex document". This resulted in solutions that lacked detail and were too brief for the lecturer's liking. In a fresh chat, the exam paper PDF was reuploaded with the revised prompt: "Provide written solutions to the given exam paper, *breaking things down into small steps*. Present your answer in a latex document". The output initially looked promising, but ChatGPT stopped unexpectedly after generating solutions for the first half of the paper. The third iteration used the prompt: "Provide written solutions to the given exam paper, breaking things down into small steps. *Solve every single question part in detail.* Present your answer in a latex document". This time, ChatGPT produced full, detailed solutions to the entire paper.

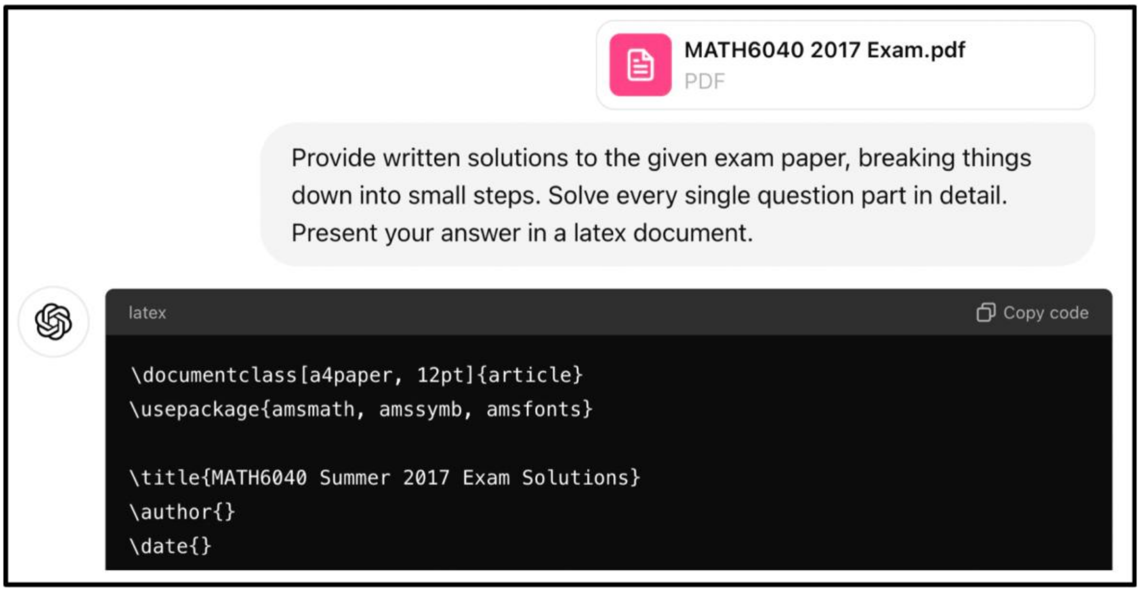

Figure 1. Uploading a PDF file of a maths exam and asking ChatGPT to return LaTeX code containing solutions.

4. Findings

Using the input and output methods outlined in section 3, ChatGPT was given the 2017 summer exam paper for the module. It generated a complete LaTeX solution document in 3 minutes and 36 seconds. For two question parts that required the drawing of a graph, the LaTeX document included a textual description rather than an image. A follow up prompt was provided explicitly requesting image files, which ChatGPT successfully generated. After careful review of the solutions, ChatGPT was found to have made errors in 6 of the 28 question parts: two miscalculations, one misread question, two solutions with incomplete final steps, and one instance where the correct answer was obtained but the workings were incorrect. When graded by the module's lecturer, ChatGPT's solutions would have achieved a score of 86%.

The code was copied into a LaTeX editor and refined by the module's lecturer with two main objectives: ensuring mathematical correctness and aligning the solution style with examples presented in class. To resolve the misread question error, an image file of the question was reuploaded, which ChatGPT correctly interpreted on the second attempt. If ChatGPT's original solution method deviated significantly from classroom examples, the question was reuploaded with a prompt which specified the preferred approach. The process of reviewing, reprompting as needed, editing, and formatting took a total of 2 hours and 32 minutes.

For comparison, the lecturer also created step-by-step solutions to the 2018 summer exam paper without assistance from ChatGPT. To minimise the time spent on the task, the lecturer decided to electronically handwrite the solutions on an iPad, the same method that had been used for creating the modules lecture notes. Since many exam questions closely resembled examples from the lecture notes, existing content could be copied and edited to produce the exam solutions. Creating the handwritten solution document to the 2018 exam paper took a total of 4 hours and 31 minutes. Due to the time savings from copy and pasting existing handwritten content, manually producing the solutions in LaTeX would likely have taken significantly longer.

It should be noted that the experiment design has several limiting factors: the comparison involved two different source exam papers, the output formats were not consistent, and the exams' questions focused only on specific engineering maths topics. This experiment serves as a proof of concept that utilising generative AI can lead to significant time savings, but further investigation is required to determine how broadly this result applies.

5. Strengths of ChatGPT Generated Solutions

This section explores the advantages of using ChatGPT for generating maths solutions. The reflections here, as well as in the next section, come from various interactions with ChatGPT extending beyond the case study in section 4.

5.1 Speed

Models such as ChatGPT-4o generate output remarkably quickly. In this case study, ChatGPT-4o produced full solutions to an exam paper in 3 minutes and 36 seconds, requiring just 3% of the two-hour time limit available to students when sitting the exam.

5.2 Accuracy

Each mistake in the generated solutions requires time and effort to correct, so fewer errors result in a lower overall time commitment. In this case study, ChatGPT-4o demonstrated strong accuracy, producing mathematically correct solutions for 78.6% of the questions on the exam paper. As more advanced models are developed, this accuracy is likely to improve.

5.3 Quality of Explanation

For years, tools like WolframAlpha have been able to solve mathematical problems accurately. However, the step-by-step solutions provided are typically written in dense mathematical notation that can be challenging for novice learners to understand. A major strength of ChatGPT is its ability to explain solutions in simple language while carefully sequencing solution steps in a clear and structured manner. In Figure 2, ChatGPT's is tasked with solving a linear equation. The solution is well structured and effectively explains each step of the process in plain English.

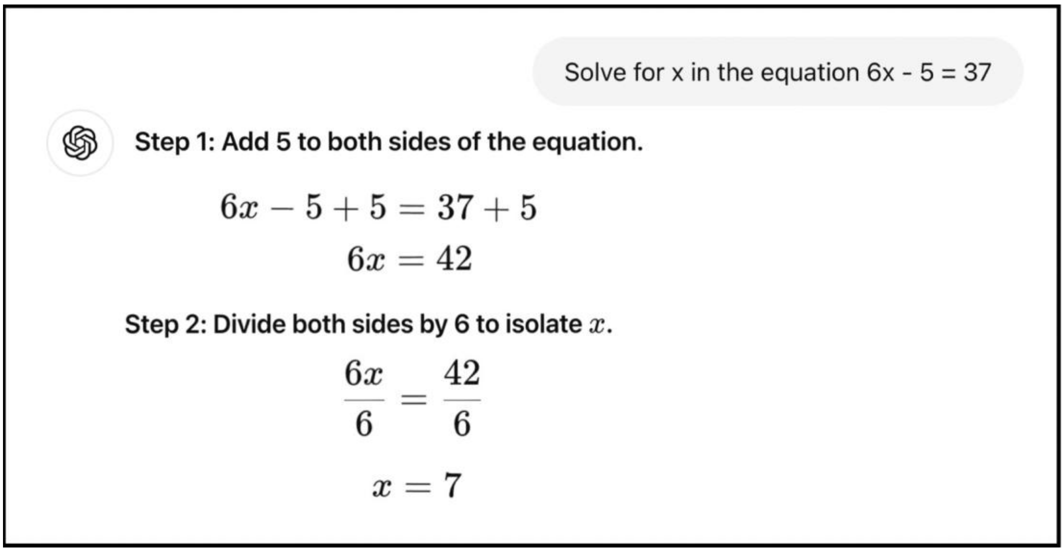

Figure 1. Example of ChatGPT-4o correctly solving a linear equation.

In Figure 3, ChatGPT is asked to differentiate an expression requiring the product rule. Instead of immediately performing the calculation, it first explains the method it is going to use. This puts emphasis on the key mathematical insight needed to solve the problem. ChatGPT proceeds to split the product rule application into three clear steps, then performs and explains each one.

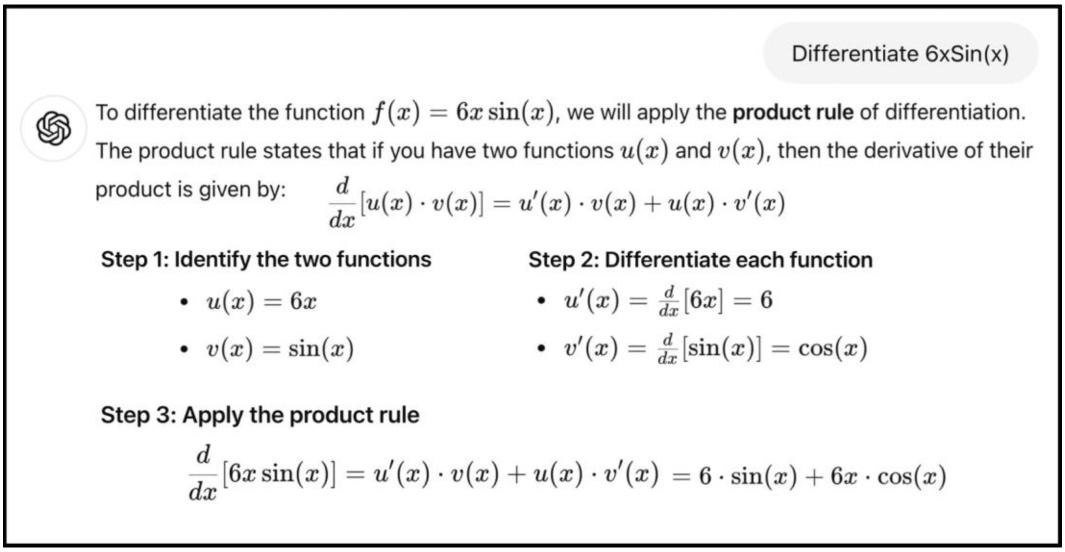

Figure 3. Example of ChatGPT-4o correcly applying the product rule.

6. Limitations of ChatGPT generated solutions

A review of ChatGPT's mathematical errors reveals several recurring patterns. This section highlights three common pitfalls, each explained and illustrated with an example.

6.1 Calculation Errors

A major flaw of older ChatGPT models is their inability to reliably perform numerical computations. In Figure 4, ChatGPT-3.5 was prompted to calculate 0.72 raised to the power of 9 three different times. It yielded three different results, none of which were correct.

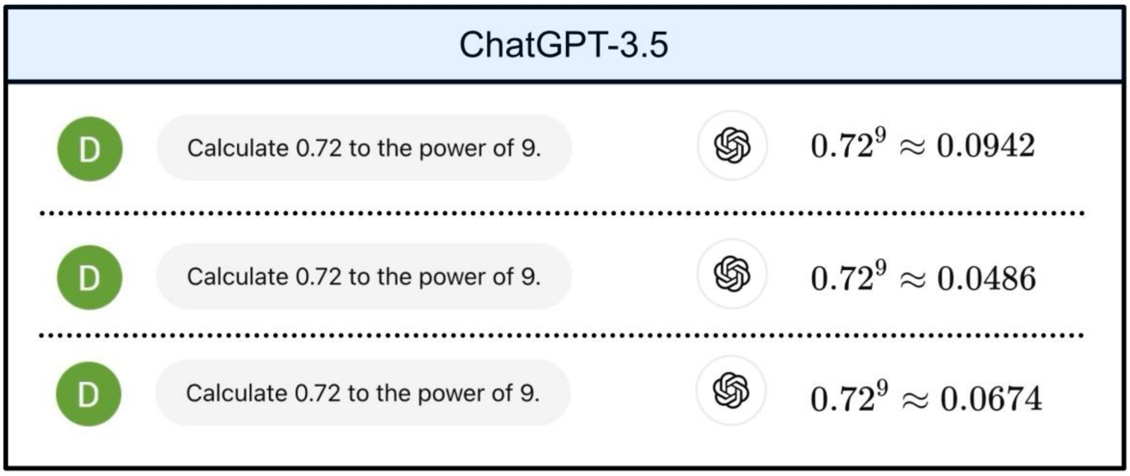

Figure 4. ChatGPT-3.5 struggles with basic computations.

The computational limitations of earlier models, such as ChatGPT-3.5, are well documented. Raftery (2023) found that manually correcting ChatGPT-3.5's calculation errors using a hand calculator improved its average performance on a series of online quizzes from 35% to 72%.

Newer models, such as ChatGPT-4o, incorporate a code interpreter that utilises Python to perform numerical computations. Given Python's reliability in handling such calculations, computation errors are effectively eliminated in models equipped with this functionality. Figure 5 showcases ChatGPT-4o's code interpreter window, which is used to accurately compute 0.72 raised to the power of 9.

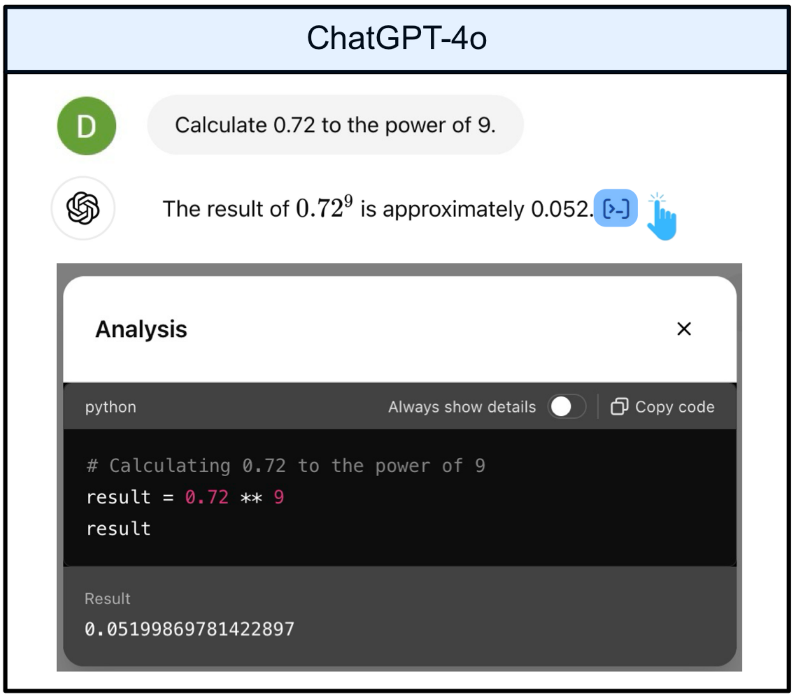

Figure 5. ChatGPT-4o utilises Python to accurately perform numerical calculations.

When using ChatGPT for numerical computations, it is important to check whether the model version includes a code interpreter, as this significantly affects calculation accuracy.

6.2 Incorrect Workings

In some cases, the solution provided by ChatGPT starts correctly, produces the correct answer, but contains mistakes in the intermediate steps. In Figure 6, ChatGPT is prompted to calculate the determinant of a 3x3 matrix. It correctly states a formula for calculating the determinant and arrives at the correct answer of 0. However, the intermediate workings contain multiple errors.

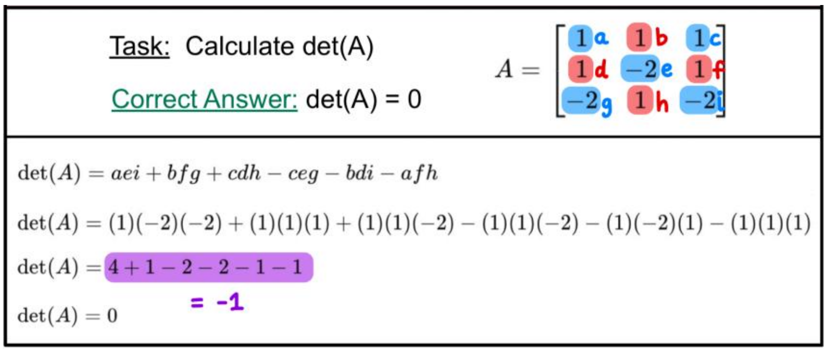

Figure 6. ChatGPT starts correctly and arrives at the correct final answer, but has incorrect workings inbetween.

ChatGPT's text-based responses are known to be highly persuasive, even when conveying information that is factually incorrect. This concern extends to ChatGPT's mathematical reasoning. Even if a solution appears correct at first glance, it is important to thoroughly verify every step to ensure correctness.

6.3 Overcomplicated Answers

The more powerful ChatGPT models become, the greater the risk of them overcomplicating their answers. Figure 7 compares ChatGPT-3.5 and ChatGPT-4o's responses to the following prompt: “A person has the option of taking one of three routes to work, A, B or C. The probability of taking route A is 35%, and B is 25%. The probability of being late for work if she goes by route A is 10% and similarly by route B is 5% and route C is 2%. Draw a tree diagram to illustrate the outcomes and their probabilities.”

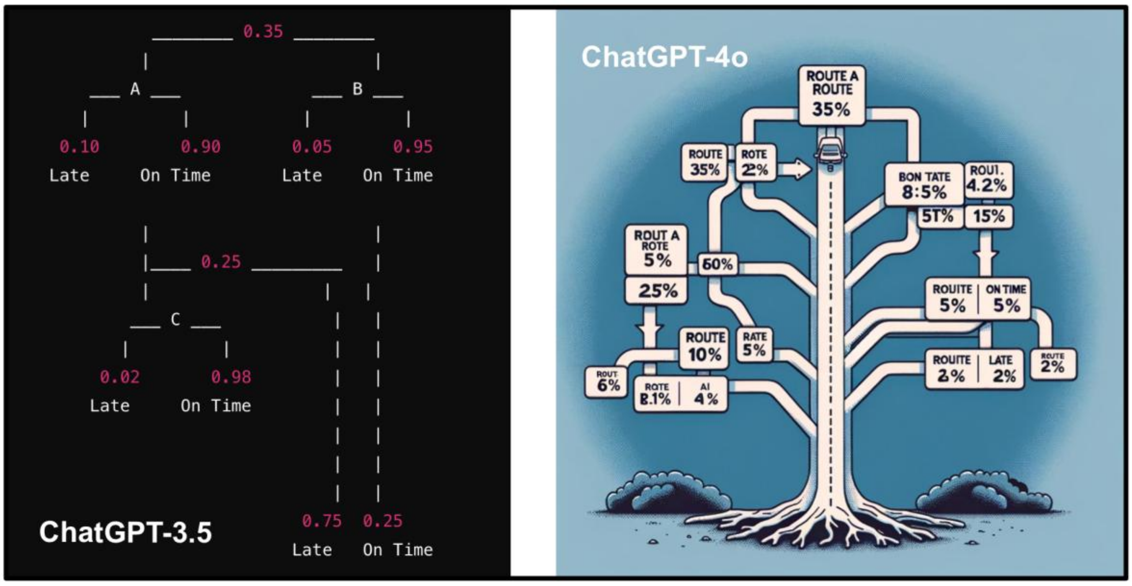

Figure 7. An example where ChatGPT-4o overcomplicates its response, leading to worse performance than ChatGPT-3.5.

While not entirely correct, ChatGPT-3.5 makes a reasonable attempt at the problem. Notably, it infers information beyond what is directly stated in the question, such as correctly determining that if the probability of being late on route A is 10% (0.1), then the probability of being on time must be 90% (0.9). ChatGPT-4o generates a visually appealing but mathematically useless depiction of a tree with a car driving down its trunk. In most cases, this issue can be resolved by reprompting for a simpler answer or specifying the image generation method, such as using the Matplotlib library in Python.

7. Conclusions

Using a ChatGPT-4o-generated draft as a starting point for an exam solutions document led to a total creation time of 2 hours 36 minutes, compared to 4 hours 31 minutes without using the assistance of ChatGPT - a 42% reduction in the time needed.

The format of each solution document was selected according to the lecturer’s preference, with the aim of minimising the total time required. This resulted in two different formats - a typed LaTeX document with ChatGPT’s assistance versus electronically handwritten solutions without. A fairer comparison would involve creating LaTeX documents in both cases, though it is believed this would result in an even greater reduction in the time required.

An issue not addressed in this case study is the quality of the solution documents. While every effort was made to ensure correctness, their effectiveness in supporting learning was not assessed. Future work could involve surveying students who used these resources for revision to determine their perceived usefulness.

ChatGPT-4o is highly effective at generating maths solutions, offering quick responses and well-structured explanations. However, it has limitations, including the possibility of calculation errors, incorrect workings, and overly complex answers. Given the risk of unnoticed errors hindering learning, it is advisable for a subject expert to verify the accuracy of ChatGPT-generated maths solutions before they are shared with novice learners.

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