Supporting student success: A multiple methods approach to mathematics support engagement and evaluation

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This thesis is submitted to University College Dublin in fulfilment of
the requirements for the degree of Doctor of Philosophy in Mathematics and
Statistics

School of Mathematics and Statistics

Head of School: Professor Nial Friel

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Research Studies Panel members:

Professor Edward A. Cox

Professor Claire Gormley

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Abstract

Mathematics and statistics support (MSS)—an established part of academic support in most English-speaking universities—is shown to increase students grades, retention, and confidence, yet often students engage too late or not at all, an issue exacerbated by the COVID-19 pandemic. This research aims to increase student engagement in MSS in University College Dublin (UCD) and evaluate the impact of that engagement in the context of the changing nature of MSS.

Firstly, the operation of the UCD Maths Support Centre and its impact on students' grades is studied. Moderation analysis of over 12,000 students' mathematics grades and Maths Support Centre visits identified how MSS use positively impacted students' mathematics achievement.

Secondly, the first systematic scoping literature review of MSS evaluation literature explores the impact of MSS on students internationally. A range of MSS formats, study designs, and results but also limitations were found.

Thirdly, thematically analysed interviews of Irish and Australian students and tutors and a later survey of students capture the key issues around online MSS and combining online and in-person support. Themes include reduced MSS use online, mathematics being different, and pedagogical changes, as well as preferences for in-person support but an acknowledgement of online MSS benefits.

Finally, a reflective, student-centred cycle of design was used to design MathsFit, an online suite of mathematics supports for UCD first-year non-specialist mathematics students. MathsFit seeks to identify and aid those who would most benefit from MSS during their transition to university mathematics. Analysis of over 3000 student participants from three iterations of MathsFit is presented focusing on the identification of "at-risk" students, the areas of mathematics they struggle with, and their engagement with MathsFit and the UCD Maths Support Centre. Also, differences in students' engagement and attainment due to demographic factors are identified, and comparisons between MSS engagement during MathsFit iterations (2020-2022), and in previous years (2015-2019) are made. The results reveal low failure rates, struggles with algebra and calculus, previous mathematics education impacting engagement and attainment, and mixed uptake of support.

Overall, this research provides conclusions about MSS impact from the year 2000 onwards with a particular focus on 2020-2023 establishing how MSS supports student success.

Statement of Original Authorship

I hereby certify that the submitted work is my own work, was completed while registered as a candidate for the degree stated on the Title Page, and I have not obtained a degree elsewhere on the basis of the research presented in this submitted work.

Collaborations

Chapter 2: The moderation analysis of Leaving Certificate grades, UCD mathematics module grades, and UCD Maths Support Centre visits was completed as part of my assessment for a module taught by Associate Professor Laura Taylor who provided feedback on my analysis and the conference paper "Evaluating the impact of mathematics support using moderation". The data used in the analysis was previously organised and analysed by Chang Liu for her masters dissertation under the supervision of Associate Professor Anthony Cronin. Further data organisation and all analysis presented in the conference paper, and in this chapter was completed by me. My analysis did not depend on Chang Liu's analysis in any way, the work presented in this thesis and Chang Liu's thesis are two separate analyses of the same dataset.

Chapter 3: The work in this chapter was done in collaboration with Assistant Professor Emma Howard and Associate Professor Anthony Cronin. Anthony Cronin led the identification of databases and other sources to search for publications. Emma Howard led the database search. Most aspects of the review including the development of the protocol and the literature search with the screening process and data extraction were conducted collaboratively. I created the initial proposal of objectives and selection criteria (the protocol) and reviewed the majority of publications at each stage of screening and data extraction. I conducted the analysis and synthesis of results.

Chapters 4, 5 and 6: The work in these chapters was done in collaboration with Associate Professor Leanne Rylands, Dr Jim Pettigrew, Mr Donald Shearman, and Associate Professor Anthony Cronin. Jim Pettigrew collated the literature reviews around online MSS in addition to obtaining ethical approval for Western Sydney University participants. Jim Pettigrew, Leanne Rylands and Don Shearman assisted in recruiting participants and provided background information for the research context. They, with Anthony Cronin, provided validation of the qualitative analysis in Chapters 4 and 5 and assisted with the survey design in Chapter 6. I conducted all other aspects of these chapters.

Chapters 7, 8 and 9: The work in these chapters was done by me under Anthony Cronin's supervision. A number of colleagues assisted with the practical implementation of the action research and they are thanked in the acknowledgements.

The acknowledgement of authorship forms follow for each paper presented as a chapter of this thesis.

Chapter 2: Evaluating the impact of mathematics support using moderation

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2. Student Contribution to the Paper	
This co-authorship declaration applies to the following paper: Evaluating the impact of mathematics support using moderation	
Percentage Contribution %: 90% Outline of student contribution for each section of paper: Abstract: 95%: Claire wrote the abstract and edited it based on feedback from co-authors. Introduction: 95%: Claire wrote the introduction and edited it based on feedback from co-authors. Literature Review: 95%: Claire wrote the literature review and edited it based on feedback from co-authors. Methodology: 80%: Claire wrote the methodology and edited it based on feedback. The data organisation process detailed was created by Chang Liu under the supervision of Anthony Cronin. Data Analysis: 90%: Claire wrote this and edited it based on feedback. The analysis was designed based on advice from Laura Taylor. Results: 95%: Claire compiled the results and edited it based on feedback from co-authors. The analysis presented was completed by Claire. Discussion and Conclusion: 95%: Claire wrote this and edited it based on feedback from co-authors. Figure 1: 95%: Claire created this figure and edited it based on feedback from Anthony Cronin. Figure 2: 95%: Claire created this figure and edited it based on feedback from Anthony Cronin. Figure 3: 95%: Claire created this figure and edited it based on feedback from Anthony Cronin. Table 1: 95%: Claire created this table and edited it based on feedback from Anthony Cronin. Table 2: 95%: Claire created this table and edited it based on feedback from Anthony Cronin.	
3. Other Authors contribution to the paper	
Author	Contribution
Anthony Cronin	5% Contribution: Supervised the organisation of the data (completed by Chang Liu) and the data analysis presented in this paper. Provided detailed feedback and suggested edits for the paper.
Laura Taylor	2.5% Contribution: Provided feedback on the analysis process and results, and the later versions of the paper.
Chang Liu	2.5% Contribution: Completed the data organisation of the data presented in this paper. Her analysis of this data was entirely separate to the analysis presented in this paper.

Chapter 3: A scoping literature review of the impact and evaluation of mathematics and statistics support in higher education

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Title of Research thesis: Supporting student success: A multiple methods approach to mathematics support engagement and evaluation	
2. Student Contribution to the Paper	
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Percentage Contribution: 80% Outline of student contribution for each section of paper: Abstract: 90%: Claire wrote the abstract and edited it based on feedback from co-authors. Background: 90%: Claire wrote the background and edited it based on feedback from co-authors. Method: 90%: Claire wrote the method and edited it based on feedback from co-authors. Results: 85%: Claire compiled the results and edited it based on feedback from co-authors. The analysis presented was completed by Claire based on the search, screening, and data extraction which was completed collaboratively. Claire completed the majority of the screening and data extraction of publications. Discussion: 85%: Claire wrote the discussion and edited it based on feedback from and discussion with co-authors. Future directions for MSS evaluation research: 85%: Claire wrote this and edited it based on feedback from and discussion with co-authors. Conclusion: 90%: Claire wrote the conclusion and edited it based on feedback from co-authors. Figure 1: 95%: Claire created this figure and edited it based on feedback from co-authors. Figure 2: 95%: Claire created this figure and edited it based on feedback from co-authors. Figure 3: 95%: Claire created this figure and edited it based on feedback from co-authors. Figure 4: 40%: Emma Howard initially created this figure based on data provided by Claire. Claire later edited the figure. Table 1: 95%: Claire created this table and edited it based on feedback from co-authors. Table 2: 95%: Claire created this table and edited it based on feedback from co-authors. Appendices: 85%: The search strings were co-created by Claire and Emma Howard. Claire created the tables and edited them based on feedback from co-authors.	

3. Other Authors contribution to the paper	
Author	Contribution
Emma Howard	15% Contribution: Led the database search, aided development of the protocol, screened abstracts and full papers, participated in data extraction, created a figure, and provided feedback on the paper.
Anthony Cronin	5% Contribution: Supervised the research process, led the identification of databases and other sources, aided development of the protocol, screened abstracts and full papers, participated in data extraction, and provided feedback on the paper.

Chapter 4: Mathematics is different: student and tutor perspectives from Ireland and Australia on online support during COVID-19

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Percentage Contribution %: 70% Outline of student contribution for each section of paper: Abstract: 90%: Claire wrote the abstract and edited it based on feedback from co-authors. Introduction: 90%: Claire wrote the introduction and edited it based on feedback from co-authors. Literature Review: 20%: Claire provided feedback on the initial version of the literature review by Jim Pettigrew and Anthony Cronin, and later edited it based on feedback from co-authors. Background: 50%: Claire wrote the UCD portion of this and edited the Western Sydney University portion which was written by Leanne Rylands and Don Shearman. Method: 90%: The interview questions were collaboratively designed. Claire conducted the interviews, created the transcripts, and designed the qualitative coding process. Claire wrote the methodology with feedback from co-authors. Results: 90%: Claire completed the analysis with the co-authors assisting with coding. Claire collated the results with feedback from co-authors. Discussion: 85%: Claire wrote the discussion with feedback from and discussion with co-authors. Conclusion: 90%: Claire wrote the conclusion with feedback from co-authors. Figure 1: 95%: Claire created this figure and edited it based on feedback from co-authors. Figure 2: 95%: Claire created this figure and edited it based on feedback from co-authors.	
3. Other Authors contribution to the paper (Outline briefly the contribution of other authors to the paper)	
Author	Contribution
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Anthony Cronin	10% Contribution: Supervised the research process, aided participant recruitment, provided background context, aided the coding and checking of interview transcripts, and provided feedback on the paper as a whole.
Leanne Rylands	5% Contribution: Aided participant recruitment, provided background context, aided the coding and checking of interview transcripts, and provided feedback on the paper as a whole.
Donald Shearman	5% Contribution: Aided participant recruitment, provided background context, aided the coding and checking of interview transcripts, and provided feedback on the paper as a whole.

Chapter 5: Mathematics is different: student and tutor perspectives from Ireland and Australia on online support during COVID-19

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Percentage Contribution %: 70% Outline of student contribution for each section of paper: Abstract: 90%: Claire wrote the abstract and edited it based on feedback from co-authors. Introduction: 90%: Claire wrote the introduction and edited it based on feedback from co-authors. Literature Review: 20%: Claire provided feedback on the initial version of the literature review by Jim Pettigrew and later edited it based on feedback from co-authors. Background: 50%: Claire wrote the UCD portion of this and edited the Western Sydney University portion which was written by Leanne Rylands and Don Shearman. Method: 90%: The interview questions were collaboratively designed. Claire conducted the interviews, created the transcripts, and designed the qualitative coding process. Claire wrote the methodology with feedback from co-authors. Results: 90%: Claire completed the analysis with the co-authors assisting with coding. Claire collated the results with feedback from co-authors. Discussion: 85%: Claire wrote the discussion with feedback from and discussion with co-authors. Conclusion: 90%: Claire wrote the conclusion with feedback from co-authors. Figure 1: 95%: Claire created this figure and edited it based on feedback from co-authors. Figure 2: 95%: Claire created this figure and edited it based on feedback from co-authors.	
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Jim Pettigrew	10% Contribution: Collated the literature review, obtained ethical approval from Western Sydney University, aided participant recruitment, provided background context, aided the coding and checking of interview transcripts, and provided feedback on the paper as a whole.
Anthony Cronin	10% Contribution: Supervised the research process, aided participant recruitment, provided background context, aided the coding and checking of interview transcripts, and provided feedback on the paper as a whole.
Leanne Rylands	5% Contribution: Aided participant recruitment, provided background context, aided the coding and checking of interview transcripts, and provided feedback on the paper as a whole.
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Chapter 6: Optimising the blend of in-person and online mathematics support: the student perspective

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2. Student Contribution to the Paper	
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Percentage Contribution %: 70% Outline of student contribution for each section of paper: Abstract: 90%: Claire wrote the abstract and edited it based on feedback from co-authors. Introduction: 90%: Claire wrote the introduction and edited it based on feedback from co-authors. Literature Review: 30%: Claire provided feedback on the initial version of the literature review by Jim Pettigrew and Anthony Cronin and later edited it based on feedback from co-authors. Mathematics and statistics support at the two universities: 50%: Claire wrote the UCD portion of this and edited the Western Sydney University portion (written by Leanne Rylands and Don Shearman). Methodology: 85%: The survey and other methodological aspects were collaboratively designed. Claire wrote the methodology with feedback from co-authors. Results: 95%: Claire completed the analysis and collated the results with feedback from co-authors. Discussion: 90%: Claire wrote the discussion with feedback from co-authors. Conclusion: 90%: Claire wrote the conclusion with feedback from co-authors. Figure 1: 95%: Claire created this figure and edited it based on feedback from co-authors. Figure 2: 95%: Claire created this figure and edited it based on feedback from co-authors. Figure 3: 95%: Claire created this figure and edited it based on feedback from co-authors. Figure 4: 95%: Claire created this figure and edited it based on feedback from co-authors. Figure 5: 95%: Claire created this figure and edited it based on feedback from co-authors. Table 1: 95%: Claire created this table and edited it based on feedback from co-authors. Table 2: 95%: Claire created this table and edited it based on feedback from co-authors. Table 3: 95%: Claire created this table and edited it based on feedback from co-authors. Table 4: 95%: Claire created this table and edited it based on feedback from co-authors. Appendix: 95%: Claire created the tables and edited them based on feedback from co-authors.	
3. Other Authors contribution to the paper	
Author	Contribution
Jim Pettigrew	10% Contribution: Co-collated the literature review, obtained ethical approval from Western Sydney University, aided participant recruitment, provided background context, participated in the survey design process, and provided feedback on the paper as a whole.
Anthony Cronin	10% Contribution: Supervised the research process, co-collated the literature review, aided participant recruitment, provided background context, participated in the survey design process, and provided feedback on the paper as a whole.

Leanne Rylands	5% Contribution: Aided participant recruitment, provided background context, participated in the survey design process, and provided feedback on the paper as a whole.
Donald Shearman	5% Contribution: Aided participant recruitment, provided background context, participated in the survey design process, and provided feedback on the paper as a whole.

Chapter 7: Promoting student support engagement: The design evolution of MathsFit, a diagnostic and support programme

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2. Student Contribution to the Paper	
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Percentage Contribution %: 95% Outline of student contribution for each section of paper: Abstract: 95%: Claire wrote the abstract and edited it based on feedback from Anthony. Introduction: 95%: Claire wrote the introduction and edited it based on feedback from Anthony. Motivation for MathsFit: 95%: Claire wrote this and edited it based on feedback from Anthony. Literature Review: 95%: Claire wrote this and edited it based on feedback from Anthony. Design: 95%: Claire wrote this and edited it based on feedback from Anthony. Results: 95%: Claire completed the analysis and collated the results with feedback from Anthony. Discussion: 95%: Claire wrote the discussion with feedback from Anthony. Future Plans: 95%: Claire wrote the discussion with feedback from Anthony. Conclusion: 95%: Claire wrote the conclusion with feedback from Anthony. Figure 1: 95%: Claire created this figure and edited it based on feedback from Anthony. Figure 2: 95%: Claire created this figure and edited it based on feedback from Anthony. Figure 3: 95%: Claire created this figure and edited it based on feedback from Anthony. Figure 4: 95%: Claire created this figure and edited it based on feedback from Anthony. Figure 5: 95%: Claire created this figure and edited it based on feedback from Anthony. Figure 6: 95%: Claire created this figure and edited it based on feedback from Anthony. Figure 7: 95%: Claire created this figure and edited it based on feedback from Anthony. Figure 8: 95%: Claire created this figure and edited it based on feedback from Anthony. Table 1: 95%: Claire created this table and edited it based on feedback from Anthony. Table 2: 95%: Claire created this table and edited it based on feedback from Anthony. Table 3: 95%: Claire created this table and edited it based on feedback from Anthony. Table 4: 95%: Claire created this table and edited it based on feedback from Anthony. Table 5: 95%: Claire created this table and edited it based on feedback from Anthony. Table 6: 95%: Claire created this table and edited it based on feedback from Anthony. Table 7: 95%: Claire created this table and edited it based on feedback from Anthony. Table 8: 95%: Claire created this table and edited it based on feedback from Anthony. Table 9: 95%: Claire created this table and edited it based on feedback from Anthony. Appendix: 95%: Claire collated these materials, created in the design process with Anthony.	
3. Other Authors contribution to the paper	
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Anthony Cronin	5% Contribution: Supervised the research process, aided the design and data collection process, and provided feedback on the paper as a whole.

Chapter 8: Measuring student support engagement: Participation in MathsFit, a diagnostic and support programme

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3. Other Authors contribution to the paper	
Author	Contribution

Anthony Cronin	5% Contribution: Supervised the research process, aided the design and data collection process, and provided feedback on the paper as a whole.

Chapter 9: Evaluating student support engagement: The impact of MathsFit, a diagnostic and support programme

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2. Student Contribution to the Paper	
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3. Other Authors contribution to the paper	
Author	Contribution
Anthony Cronin	5% Contribution: Supervised the research process, aided the design and data collection process, and provided feedback on the paper as a whole.

Publications

The research in Chapters 3, 4, 5 and 6 is published in peer-reviewed journals. Chapter 2 is a published peer-reviewed conference paper. Chapters 7, 8, and 9 are papers prepared for publication but not yet submitted. Some of the material in Chapter 7 is published in peer-reviewed conference proceedings. Other conference proceedings containing work mentioned but not explicitly included in this thesis are also listed.

Journal Publications

Mullen, C., Howard, E., & Cronin, A. (2024). A scoping literature review of the impact and evaluation of mathematics and statistics support in higher education. *Educational Studies in Mathematics, 117*, 1-22. https://doi.org/10.1007/s10649-024-10332-6

Mullen, C., Pettigrew, J., Cronin, A., Rylands, L., & Shearman, D. (2021). Mathematics is different: student and tutor perspectives from Ireland and Australia on online support during COVID-19. *Teaching Mathematics and Its Applications: An International Journal of the IMA*, *40*(4), 332–355. https://doi.org/10.1093/teamat/hrab014

Mullen, C., Pettigrew, J., Cronin, A., Rylands, L., & Shearman, D. (2022). The rapid move to online support: changes in pedagogy and social interaction. *International Journal of Mathematical Education in Science and Technology*, *53*(1), 64–91. https://doi.org/10.1080/0020739X.2021.1962555

Mullen, C., Cronin, A., Pettigrew, J., Shearman, D. & Rylands, L. (2023). Optimising the blend of in-person and online mathematics support: the student perspective. *International Journal of Mathematical Education in Science and Technology.* https://doi.org/10.1080/0020739X.2023.2226153

Conference Proceedings

Howard, E,. Mullen, C., & Cronin, A. (2023). A Scoping Systematic Review of Mathematics and Statistics Support Evaluation Literature: Lessons Learnt. In A. Twohill and S. Quirke (Eds.) *Proceedings of the Ninth Conference on Research in Mathematics Education in Ireland* (pp. 69–73). Dublin City University.

Mullen, C., & Cronin, A. (2023). The evolving design and implementation of MathsFit: supporting first-year non-specialist mathematics students. In P. Drijvers, C. Csapodi, H. Palmér, K. Gosztonyi, & E. Kónya (Eds.), *Proceedings of the Thirteenth Congress of the European Society for Research in Mathematics Education (CERME13)* (pp. 2463–2470). Alfréd Rényi Institute of Mathematics and ERME.

Mullen, C., & Cronin, A. (2022). A university mathematics transition programme designed to increase student engagement with mathematics support. In J. Hodgen, E. Geraniou, G. Bolondi & F. Ferretti. (Eds.), *Proceedings of the Twelfth Congress of the European Society for Research in Mathematics Education (CERME12)* (pp.2463–2470). Free University of Bozen-Bolzano and ERME.

Mullen, C., Cronin, A., Taylor, L., & Liu, C. (2021). Evaluating the impact of mathematics support using moderation. In M. Kingston and P. Grimes (Eds.) *Proceedings of the Eighth Conference on Research in Mathematics Education in Ireland* (pp. 284–291). Dublin City University.

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Assistant Professor Emma Howard has been not only an excellent collaborator in the completion of the scoping literature review but also a great source of advice particularly in the latter years of my PhD. She is a wonderful role model and colleague.

Thank you to the UCD library staff who assisted with database information and locating manuscripts for the scoping literature review. Additionally, I would like to thank the following colleagues for their generosity of time and spirit in sourcing manuscripts for the scoping literature review: Alejandro Gonzales Martin, Gisele Kaiser, Jane Butterfield, Miroslav Lovric, and Veselin Jungic (Canada, CERME and ICME); Birgit Loch, and Donald Shearman (Australia); Carolyn Johns, and Melissa Mills (USA); Tracy Craig, and Anita Cambell (Netherlands and South Africa), Tanya Evans, and Mike Thomas (New Zealand); Marketa Matulova, Zuzana Pátíková, Josef Rebenda (Czech Republic); Tim Fukawa-Connelly, Shiv Karunakaran, Chris Rasmussen, and Aaron Weinberg (RUME); David Bowers (MSOR Connections); Emma Cliffe, Duncan Lawson, and Rob Wilson (sigma); Burkhard Alpers, Klara Ferdova, and Mike Murphy (SEFI).

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1 Introduction

Mathematics and statistics support (MSS) is an academic support service for higher education students. Common in Ireland, the UK, the USA, and Australia, MSS was developed over 20 years ago to assist students who were underprepared for undergraduate mathematical and statistical content and to ensure graduates were prepared for the 21st century data-focused employment market. As MSS became more established, research began into its impact on students, who used it and why, and MSS tutors, among other areas (Lawson et al., 2020). This thesis is the cumulation of several research studies about MSS with a focus on evaluating MSS and its impact on students. Using multiple methods, the past and present impact of MSS on students, particularly in University College Dublin, will be explored with consideration for the changing formats of MSS due to the COVID-19 pandemic.

To present the results of multiple studies, each chapter of this thesis, bar this chapter and the last chapter, is a publication or a paper prepared for publication. That is, each chapter has its own literature review, methods, results, and discussion sections with accompanying references. The background and context for each study is presented within the relevant chapter. Therefore this introductory chapter presents only a brief context of University College Dublin, where the research was conducted, and its MSS provision the Maths Support Centre before outlining the content of the upcoming chapters.

Note, throughout the thesis I will refer to myself as “the lead researcher” when multiple researchers were involved.

1.1 Research Context

This research was conducted in the School of Mathematics and Statistics, University College Dublin, Ireland. University College Dublin (UCD) is Ireland's largest university with over 38,000 students, though approximately 5,000 of those are not based in Ireland. UCD is made up of six colleges with the School of Mathematics and Statistics being in the College of Science. The formal MSS provision in UCD is called the Maths Support Centre or MSC. It opened in 2004 and is under the purview of the School of Mathematics and Statistics, though it serves students from all colleges. The MSC supports students from level 0, 1 and 2 modules, that is, preparatory, first, and second-year modules. In 2020, the year this research began, there was a population of approximately 8,600 first and second-year students in UCD (University College Dublin, 2020). The School of Mathematics and Statistics delivers 67 modules that are eligible for the MSC but, due to other modules having mathematical or statistical components, the MSC is visited by students from over 100 modules. Most of these students are non-specialist mathematics and statistics students, that is, the focus of their degree is neither mathematics nor statistics but they are obliged to study at least one module of mathematics or statistics. These modules tend to have large classes ($n > 100$).

Students are mainly accepted into Irish universities via the Central Applications Office (CAO) points system where grades from secondary school terminal examinations (the Leaving Certificate for Irish students) are converted to CAO points (CAO, 2024a). All subject examinations in the Leaving Certificate are examined at two levels, "Higher" and "Ordinary", apart from mathematics and the Irish language subject that have a third level, "Foundation". The highest grade available, a "H1" (receiving 90-100% at Higher Level), is worth one hundred points and students' best six (usually of seven) subjects' grades are converted. The highest amount of points available is 625 as, since 2016, students who sit Higher Level mathematics earn a "bonus" 25 points if they achieve between a H1 and H6 (receiving 40-100% at Higher Level) (CAO, 2024b). A university course's entry points are based on demand. If there are 50 available places on a course the first fifty students with the highest points out of the students who selected that course as their first preference on the CAO system are accepted. The amount of points that the last student to be accepted for the course becomes the course's entry points. Everyone (bar exceptions discussed below) on the course achieved that amount of points or higher. UCD courses receive high numbers of first preference choices (University College Dublin, 2024) and therefore, have comparatively higher entry points than most Irish universities.

Alternative entry routes to Irish universities are available. International students either apply through the CAO system with their secondary school examinations results or they may complete the International Foundation Year in UCD first. The Disability Access Route to Education (DARE) and Higher Education Access Route (HEAR) enable students with disabilities or whose economic or social background are underrepresented in higher education to enter UCD or the Irish university of their choice with a lower amount of points than the course requires (Irish Universities Association, 2024). There are a reserved number of places on all courses for DARE, HEAR, and Quality and Qualifications Ireland (QQI) students. QQI students have completed a relevant Higher or Advanced Certificate (level 6 on the National Qualifications Framework where the Leaving Certificate is level 5 and an ordinary Bachelor's Degree is level 7 (Quality and Qualifications Ireland, 2021). Mature students, those over the age of 23 by 1st January prior to entry, may also enter undergraduate degrees through the CAO system or they may complete an Access or Open Learning course in UCD first. There are a number of reserved places in each course for Access students. The Access to Science, Engineering, Agricultural Science, and Medicine course students have specific support sessions in the MSC.

The UCD MSC was established in 2004, with a part-time short-term contract manager and one to two tutors staffing a small office space in the John Henry Newman building. While the initial target of this service was first-year students, students from any stage or degree could drop in with no prior appointment during opening hours to ask mathematics related questions. The MSC moved location as the service expanded and in 2013/14 the MSC moved to a permanent space in the James Joyce Library. This was a more neutral and central location for the service which supported students from all six colleges of the university. From 2015 the MSC has had a permanent full-time manager. This academic role prioritises the teaching within the centre and research-informed practice and evaluation. Since October 2016, the MSC has served only level 0, 1 or 2 modules, that is, preparatory, first-year and second-year modules, to ensure these students, most affected by the secondary-tertiary transition issue (Hochmuth et al., 2021) or the mathematics problem (Lawson et al., 2020), receive enough attention from tutors.

Tutoring in the MSC is carried out by a combination of PhD students, and masters students. Final and penultimate-stage undergraduates also serve as (near-)peer tutors for first-year MSC visitors. The number of tutors hired each year has grown since the early days of the MSC, with between 14 and 29 tutors employed in the centre each year between 2011 and 2020. Between one and four tutors staff the centre at any given time during its opening hours—of which there have been approximately 40 a week since 2013.

In the drop-in format of the MSC (which was the norm until the onset of the COVID-19 pandemic in March 2020), students arrive in the centre, log-in with their student number, sit at a table, and wait for the next available tutor. Once available, the tutor greets the student and sits with them to discuss and support them in solving their mathematical or statistical problems through referencing module notes, using examples, checking students' work thus far, offering hints, suggesting online or paper resources, or other methods the tutor deems suitable. When appropriate, the tutor will leave the student to work independently for some time until the student calls the tutor back with a question or solution, or the tutor returns to check on their progress. Once a satisfactory conclusion has been reached (or the student has to leave for another class), the student will leave the centre. The tutor will then record feedback on the session with the student detailing what the problem was and how it was resolved, noting any particular mathematical/statistical difficulties the student had. At various times of the week, and the semester, the MSC is busier than normal and on these occasions, tutors may group students working on similar problems together to use their time more efficiently and to encourage collaboration. Students may also attend as a group.

Appointment-based sessions were introduced in the MSC in 2020, due to the move to online learning caused by COVID-19, which will be detailed in Chapter 4. In-person appointments work in a similar way to a drop-in session. Tutors can see students' bookings in an electronic calendar with details of the time, module, and purpose of their visit. Priority is given to students with an appointment so they face less of a wait time, while drop-in students will queue and be seen when a tutor becomes available. Students with appointments have a guaranteed 30 minutes with the tutor.

Since opening, MSC staff have recorded which students visit, when, what module they are registered to, and their topic of difficulty. Data collection of the length of each students' visit, further background information and tutors' comments on their mathematical difficulties was in effect from 2009 to 2015 through a web application. Tutors recorded students' information and some details of their mathematical difficulties. Lecturers were also able to access this application to see anonymous tutor entries for their module. In Spring 2015 a new MSC management system was created which allowed more rigorous data collection. Specific timing of visits—when students log in, when tutors select a student in the system, when students are paused (and for how long), and when the tutor ends the "session" of help—are recorded by the system. Tutors' feedback about how the student was assisted is aided by the categorisation of topics. While this type of data was previously collected, the new bespoke system allowed greater ease in collection for the tutors and automatic data retention. The new system was linked to the UCD central registry database allowing tutors to see what modules a student was studying once the student signed in with their student number. Also, when signing in, students can consent for their data to be used in evaluative research at the MSC. This development aided the creation of annual reports published on the MSC website[1], and research into the impact of the MSC.

Figure 1.1 displays the number of unique visitors and total number of visits to the MSC each year between 2013 and 2022 (the final year of data collection for this thesis). Highlighted through different background colours are the different formats of the MSC over these years—fully in-person until March 2020, online only from March 2020 until September 2021, and a combination of in-person and online offerings since then. The exploration of these changes in format, the impact they had on the MSC, and students' and tutors' opinions about them will be explored in Chapters 4, 5 and6. Chapter 2 analyses MSC data from Spring 2015 and Autumn 2019, while Chapter 8 studies

[1] https://www.ucd.ie/msc/missionstatementandannualreports/

MSC data from 2015/16 to 2022/2023. Analysis presented in Chapter 9 involves MSC data from 2020/21 to 2022/23.

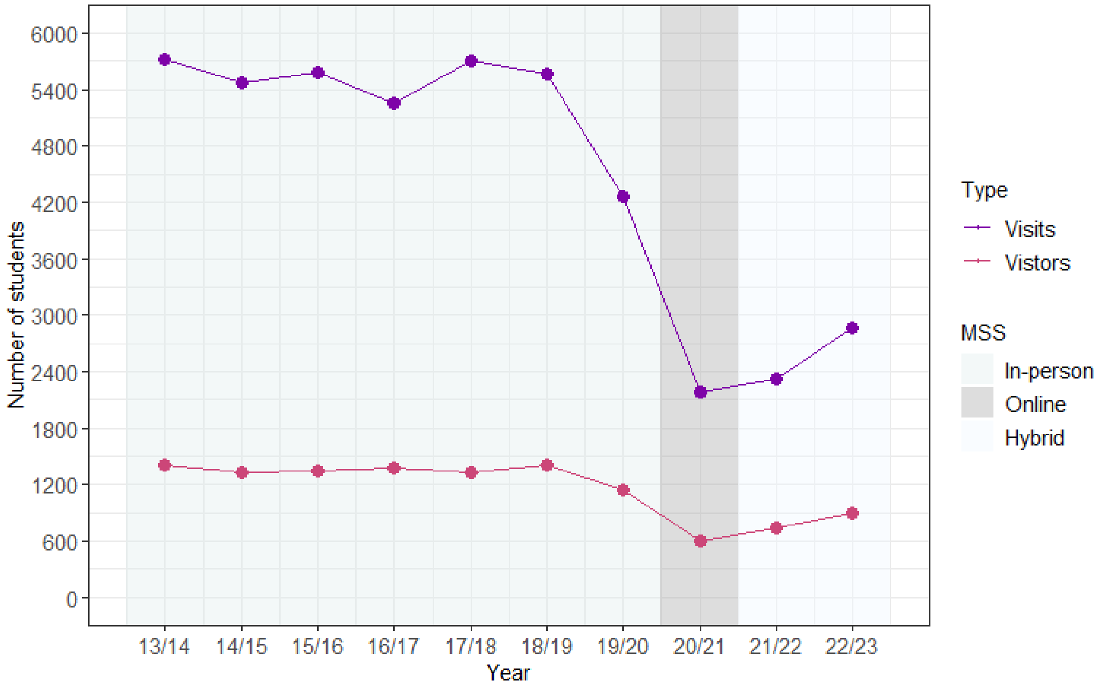

Figure 1.1: Number of visits and visitors to the MSC from 2013 to 2022 with the format of MSS available shown.

1.2 Thesis outline

This thesis is a collection of eight published/publishable papers which are presented in Chapters 2-9 with an accompanying critical and theoretical overview of the research as whole which is offered in Chapter 10. Each chapter has its own research question(s), the results of which collate to answer the overarching research question guiding this PhD research:

1. How do students engage with mathematics and statistics support, what affects this engagement, and what impact does this engagement have?

The content of each chapter will now be outlined with their research question(s).

Chapter 2 presents an impact analysis of visiting the MSC on the relationship between students' prior school mathematics results and university mathematics module results. Moderation analysis is used to answer the research questions:

1. Does visiting the MSC accentuate the positive relationship between students' prior school mathematics results and their university mathematics module results?
2. If so, for which students is it most beneficial and does the number of MSC visits matter?

Chapter 3 presents the method and results of a scoping review of MSS evaluation literature with a focus on student impact. The following four research questions are answered.

1. When, where, and how are MSS evaluation studies published?
2. What are the different formats of MSS evaluated in these studies?

3. How and what data are collected for MSS evaluation, and is there potential for bias?
4. What are the analysis methods used in MSS evaluation and what results have been found?

Chapter 4 investigates tutors' and students' experience of online MSS during 2020. Participants from UCD and Western Sydney University, Australia were interviewed. Thematic analysis of the transcripts provided answers to the research question:

1. What are the issues common to an Australian and an Irish university, from both the student and tutor perspective during the COVID-19 era, pertaining to the use and future of online MSS?

Chapter 5 presents further results from the investigation into students' and tutors' experience of online MSS during 2020, answering the research question:

1. What were the effects of the rapid change to fully online MSS on pedagogy and interactions among tutors and students?

Chapter 6 explores students' opinions of online and in-person MSS formats. Students from UCD and Western Sydney University were surveyed with varying questions based on which format of MSS students had used. The research questions were:

1. How do students differ, if at all, in their opinion of MSS provision based on the format used (online/in-person)?
2. What aspects of MSS are important to students and does this differ based on the format of MSS used?
3. Which format(s) of MSS do students prefer to use in different scenarios?
4. What, if anything, would encourage exclusive users of one MSS format to use the alternative, and how can both formats be improved for the future?

Chapter 7 details the design process of MathsFit, a mathematics diagnostic and support programme for first-year, non-specialist mathematics students in UCD which commenced in September 2020. Three years of design iterations are discussed alongside student feedback and quiz results, answering the research questions:

1. How and why was MathsFit designed and how has it evolved over three research cycles?
2. How did students perform in the MathsFit quiz and are there differences in their performance across the three quiz sections?

Chapter 8 analyses MathsFit participants' support engagement during 2020, 2021 and 2022 with comparisons to engagement with the MSC pre-2020, answering the research questions:

1. How did MathsFit participants engage in the suggested mathematics support and how does this compare to MSC engagement prior to the establishment of MathsFit?

2. Are there statistically significant differences associated with gender, previous mathematics education or other factors in students' support engagement?

Chapter 9 studies the impact of MathsFit participants' support engagement on their mathematical module success via logistic regression with the research questions:

1. Does students' engagement and attainment in MathsFit, particularly their support participation in the MSC and Refresher Course affect their attainment in their mathematics module?
2. What other demographic or previous education factors have a significant effect on students' mathematics module attainment?

Chapter 10 concludes the thesis with a critical and theoretical overview of the research presented in this thesis. Research limitations are discussed and future work suggested. The overarching research question is answered.

The chapters are presented in chronological order of data. Chapter 2 examines data from 2015-2019, Chapter 3 reviews publications from 2000-2022, Chapters 4 and 5 analyse interviews conducted in 2020, Chapter 6 considers surveys from 2021, while Chapters 7, 8, and 9 evaluate MathsFit design as well as student participation in 2020, 2021, and 2022. This order allows understanding of the results of MSS evaluation in UCD, then worldwide, followed by the impact of the COVID-19 pandemic on MSS engagement to facilitate full understanding of the design and evaluation of MathsFit. This order does not reflect when each study was completed. The research and publication process of Chapters 2, 4 and 5 was completed within the academic year 2020/21 with Chapters 4 and 5 completed first. The follow-on investigation in Chapter 6 began at the start of 2021/22 and was submitted for publication in December 2022. The research process presented in Chapter 3 began in December 2021 with paper submission occurring in December 2023. The work in Chapters 7, 8 and 9 was completed throughout the four years of this PhD research with the initial design of MathsFit and first cohorts of students' participation occurring in September 2020. The design evolution described in Chapter 7 occurred each year alongside survey and interview analysis. Most quantitative analysis, especially the results of Chapters 8 and 9, was conducted in 2023/24. Due to this research timeline, Chapters 4 and 5 do not reference other papers presented in this thesis. Chapter 2 references Chapters 4 and 5, while Chapter 6 builds on Chapters 4 and 5. Chapter 3 includes the publications presented in Chapters 2, 4, and 5, while Chapters 7, 8, and 9 reference all previous chapters. Chapter 10, written at the end of the entire PhD research process, aligns all eight chapters in a research overview.

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2 Evaluating the impact of mathematics support using moderation

Abstract

Mathematics and Statistics Support (MSS) has existed formally within Irish higher education for twenty years. Evaluations of the effectiveness of engaging with such student support suggest improvements in students' grades, confidence, retention, progression, completion and employability, among other factors. Distinguishing student success due to mathematics support engagement from students' other practices and use of academic resources such as lectures, tutorials, peer support and online materials is difficult. This paper presents findings from a quantitative and longitudinal analysis of visitors and non-visitors of the UCD mathematics support centre over six years. A technique from social psychology research literature known as moderation was employed to address two research questions relating to the university mathematics module grades of students who use, and do not use the institution's mathematics support centre. Moderation analysis revealed that visiting the centre more often has a significant impact on the relationship between Leaving Certificate mathematics grades and university mathematics grades. Findings indicated that using mathematics support bridges the gap between lower and higher achieving Leaving Certificate mathematics students in terms of their university mathematics results.

2.1 Introduction

Mathematics and statistics support (MSS) is an optional, non-timetabled service often in the form of a dedicated physical space where students can drop in or pre-book an appointment to gain assistance with their mathematical or statistical learning. MSS was first established in Ireland at the University of Limerick in 2001 with a similar initiative established at University College Dublin (UCD) from 2003. The latest survey of MSS provision on the island of Ireland (Cronin et al., 2016) revealed that 25 of 30 (83%) higher and further education institutions surveyed offered MSS in some form with 16 such institutions providing a dedicated centre for their support. Various attempts, both qualitative and quantitative, to evaluate MSS have been conducted throughout Ireland and internationally over the past twenty years (Matthews et al., 2013). This paper reports on a quantitative analysis, via moderation, of longitudinal UCD Mathematics Support Centre (MSC) usage data to answer the following two research questions:

1. Does visiting the MSC accentuate the positive relationship between students' prior school mathematics results and their university mathematics module results?
2. If so, for which students is it most beneficial and does the number of visits matter?

The hypothesis was that visits to the MSC did accentuate the positive relationship, with more visits meaning greater accentuation of the relationship between students' second-level school mathematics results and their university mathematics results.

2.2 Literature Review

Previous evaluative studies of the impact of MSS on students' success include both quantitative and qualitative methodologies. Dzator and Dzator (2020), utilised student surveys including open-ended questions to evidence student satisfaction and retention due to the service. Rickard and Mills (2018), and Jacob and Ni Fhloinn (2019) conducted quantitative studies linking visits to the MSS centre with improved university results while controlling for prior academic achievement. Matthews et al. (2013), and Lawson et al. (2020) have synthesised evaluative studies on the impact of MSS in their respective literature reviews. These studies show the wide ranging positive impact of MSS on learners, staff and institutions. As MSS has become a more permanent and embedded student resource within higher education there has been an evolution in scholarship from justifying centres' existence via usage figures and positive student feedback to more sophisticated evaluative techniques such as regression analysis. However, such positive student engagement with MSS and correlations with student success measured via final grades for example, do not imply a causal relationship. As Lawson et al. (2020) state "robust evaluation of the effectiveness of mathematics support alongside effective ways of engaging the disengaged remain the most important research areas in mathematics support." (p.1248). In the national context, an all-Ireland survey of MSS provision (Cronin et al., 2016) asked MSS coordinators to list their most difficult challenges in providing MSS of which "reaching the non-engaging students" and "getting students to engage earlier [in their university life]" were the top two difficulties prioritised by 19 of 22 respondents. The issue of MSS student engagement has deteriorated further with the advent of wholly online MSS brought on by the COVID-19 pandemic. In UCD attendance figures have decreased by 59% from 4,283 to 1,762 student visits for the corresponding periods of April to December in 2019 and 2020 (Mullen et al., 2021; Mullen et al., 2022). This pattern of decreased MSS engagement due to COVID-19 is replicated internationally (Hodds, 2020). Thus when the return of on-campus MSS provision resumes it will be more important than ever to evidence the effectiveness of MSS on student success for a new generation of students.

2.3 Method

Data was gathered over six academic years involving ten semesters between Spring Semester of 2015 and Autumn Semester of 2019. This data came from three sources, namely: (a) MSC visit data recording the number of visits, time of visit and the module code for each student visitor over the study period; (b) Assessment results in letter grade form for all students enrolled in the 27 modules in this study; and (c) students' prior mathematics learning achievement as measured by the Irish Leaving Certificate (LC) mathematics results. Note, that all three data sources emanate from official sources ((a) and (b) from UCD Registry and Assessment respectively and (c) from the Central Applications Office via UCD Student Records), and thus are not student self-report data.

To comply with General Data Protection Regulations (GDPR) and the university's Office of Research Ethics the data was aggregated in the form of 227 "bins". A bin represents a group of (not necessarily distinct) students with four traits in common. These traits are: (1) mathematical module type, (2) the year group of student enrolment, (3) the university letter-grade module result achieved by the student, and finally (4) the number of MSC visits the student made for that module (including non-visitors).

The 27 modules in the study fell into six types of university mathematics module which were MATH1, MATH2, ACM1, ACM2, MST and STAT. MATH1 denotes a mathematics module taken in stage one of a student's undergraduate degree programme, ACM2 denotes an Applied and Computational Mathematics subject taken in stage two, STAT denotes statistics modules taken in either stage one or two and MST denotes another type of mathematical module again taken in stage one or two. The two year-groups category from which the students first completed the module were 2015-2016/17 (five semesters) and 2017/18-2019 (five semesters). The final letter-grade result these students received in their respective module(s) are A, B, C, D, or F, where F denotes a failing grade of less than 40%. The passing grades A-D are commensurate with how UCD defines these grades numerically . Finally, the number of times the students visited the MSC for each module fall in to four distinct categories, 0, 1, 2-4 or 5+ visits in the relevant time period.

The reasons for these category choices were to maximise the number of data observations subject to preserving student anonymity in compliance with GDPR and ethical guidelines. There were 12,163 unique students in the study but 25,768 bin entries. Thus, each bin had between 3 and 1,766 entries, with a bin entry representing one module taken by one student. Hence a student can be in a bin multiple times if the student was enrolled to more than one mathematics module of this study and received the same final grade and used the MSC the same amount of times for those modules. A student can also be in multiple bins if the student was enrolled to more than one mathematics module of this study and received a different final grade and/or used the MSC a different number of times for those modules.

The LC mathematics level (Higher or Ordinary) and grade for each entry was provided by UCD Student Records. These grades were converted to a 12-point ordinal scale shown in Table 2.1. An average of these converted results was taken to create the average LC result for each bin. For example, the average LC result for bin 1 was 10.03, a H3 grade. The final university mathematics module grade was also converted from 'A to F' to '5 to 1' where A=5, B=4, C=3, D=2 and F=1. The average LC result for each bin, the final university mathematics module result for each bin (fixed for each bin e.g. bins 1 to 4 all received an A), and the number of MSC visits category for each bin, were used to create 227 observations.

Table 2.1: Conversion of Leaving Certificate grades to a 12-point scale.

Scale	Leaving Certificate grade and percentage
12	H1: Higher Level, 90-100%
11	H2: Higher Level, 80-89.99%
10	H3: Higher Level, 70-79.99%
9	H4: Higher Level, 60-69.99%
8	H5: Higher Level, 50-59.99%; O1: Ordinary Level, 90-100%
7	H6: Higher Level, 40-49.99%; O2: Ordinary Level, 80-89.99%
6	H7: Higher Level, 30-39.99%; O3: Ordinary Level, 70-79.99%
5	H8: Higher Level, 0-29.99%; O4: Ordinary Level, 60-69.99%
4	O5: Ordinary Level, 50-59.99%
3	O6: Ordinary Level, 40-49.99%
2	O7: Ordinary Level, 30-39.99%
1	O8: Ordinary Level, 0-29.99%

2.4 Data Analysis

Data were analysed using moderation, a statistical method which studies the effect of a moderator variable (in this study the number of visits to the MSC) on the relationship between an independent or predictor variable (LC mathematics result) and a dependent variable (university mathematics module result). A moderator variable can change the direction and/or the strength of the relationship between an independent and dependent variable (Baron & Kenny, 1986). Moderation can be tested using hierarchical multiple regression, looking at the interaction effect between the moderator and predictor variables and whether this interaction is significant in predicting the dependent variable.

2.5 Results

Moderation analysis was used to answer the research questions:

1. Does visiting the MSC accentuate the positive relationship between students' prior school mathematics results and their university mathematics module results?
2. If so, for which students is it most beneficial and do the number of MSC visits matter?

The significance of the interaction effect between visiting the MSC and LC grades in predicting university mathematics grades was investigated.

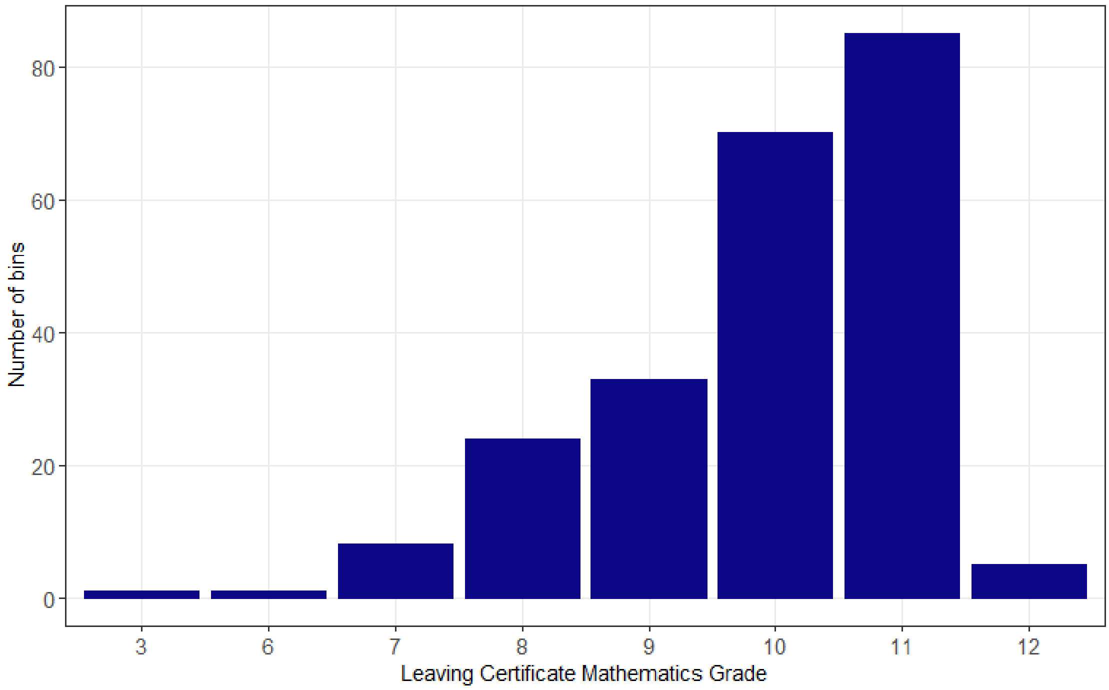

Figure 2.1: Bar chart of the bins' average Leaving Certificate mathematics results.

Figure 2.1 shows the spread of the average LC mathematics results of the bins, calculated by finding the mean of each bin’s converted LC grades and rounding these means to the nearest integer, that is, reverting to one of the twelve categories to aid understanding. The unrounded mean was used in the analysis to allow for more difference between bins. Note that the minimum UCD entry requirement mathematics grade is O6/H7 and many of the 27 modules included in the analysis require at least O2/H6 thus the bar chart is left-skewed.

Table 2.2 presents the bivariate correlations for the three variables, with * indicating p<.01. Students' Leaving Certificate mathematics results were significantly and positively correlated with their university mathematics module result and were significantly and negatively correlated with their MSC visit category. The correlation between students' university mathematics module results and MSC visit category was positive, weak and non-significant.

Table 2.2: Correlation between Leaving Certificate mathematics results, university mathematics module results, and MSC visits.

	LC mathematics result	Final module result	MSC visits
LC mathematics result	1		
Final module result	0.48*	1	
MSC visits	-0.30*	0.072	1

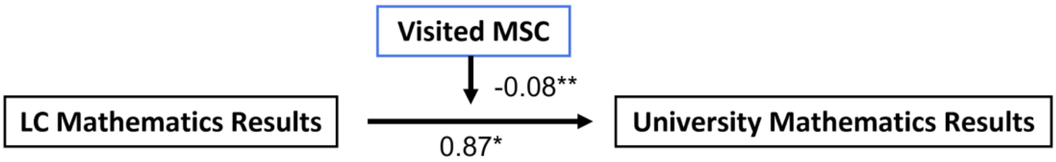

*Figure 2.2: MSC visits moderate the relationship between LC mathematics results and university mathematics module results. *unstandardised coefficient, SE = 0.12, p<.001. **unstandardised coefficient, SE = 0.03, p=.01*

Using Hayes' (2017) PROCESS model 1 in SPSS, the moderating effect of visiting the MSC was investigated, as shown in Figure 2.2. Visiting the MSC influences the strength of the relationship between LC results and university mathematics results as a significant interaction effect was found with an unstandardised coefficient of -0.08 (SE = 0.03, p = .01). Simple slopes analysis (Preacher et al., 2006), shown in Figure 2.3, reveals that the more visits a student makes to the MSC, the higher their final university mathematics grade is; this effect is more pronounced for students with lower LC results. In other words, Figure 2.3 compares the final university mathematics results of lower (one standard deviation below the mean), average (mean), and higher (one standard deviation above the mean) LC mathematics students. The positive effect of visiting the MSC is strongest for the lower achieving students (the steep blue line) compared to the higher achieving students (flatter orange line). Notably, there is a positive difference after just one visit to the MSC for all three groups. In summary, a greater number of visits to the MSC is related to higher university mathematics results, particularly for the lower achieving students.

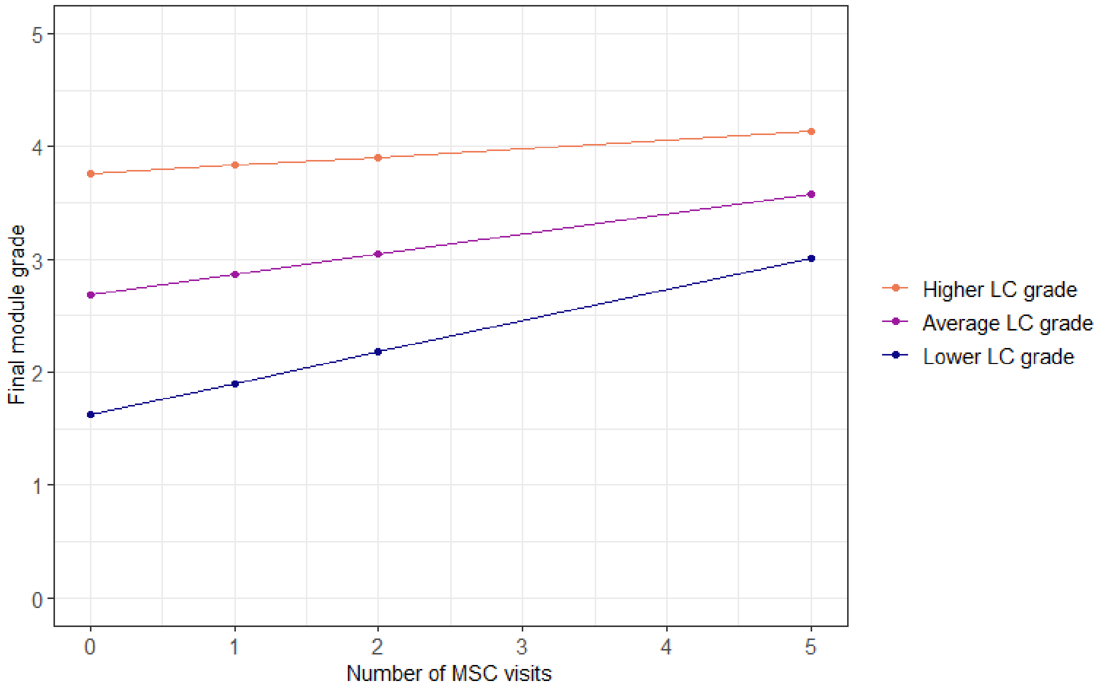

Figure 2.3: Regression of the university final mathematics result on the number of MSC Visits at specific values of LC mathematics grade is shown. Results compare for lower (1 SD below the mean), average (mean), and higher (1 SD above the mean)

2.6 Discussion and Conclusion

Determining the impact of MSS engagement on student success in subsequent examination performance is a difficult task. Simple analyses can be prone to a post hoc fallacy, whereby improvements in students' performance can be ascribed to a single intervention – or to a range of them – and do not necessarily take into account the wide variety of other potential influences on students' academic performance. Simply put, correlation is mistaken for causation. Thus rigorous and careful analyses are required to ensure the efforts of such student academic support provision is not undermined. This is achieved in the present paper by undertaking a robust statistical analysis (moderation) of a very large cohort consisting of 12,163 students over a considerable time period of six years.

This paper provides evidence that students from lower second-level school mathematical backgrounds experience a greater benefit from engaging with their institution's mathematics support centre than their higher-achieving peers. Students from higher school mathematics backgrounds experience a ceiling effect but still benefit from greater interaction with mathematics support. As hypothesised, students who had used mathematics support five times or more experienced the greatest accentuation in the relationship between their LC mathematics results and final university mathematics results but it is clear that even those who visited the MSC only once still benefited in comparison to non-users. This aligns with previous research indicating that just one visit to a MSS centre can benefit students (Jacob and Ni Fhloinn, 2019). These findings also build on existing Irish and international research demonstrating second-level mathematics performance as a predictor of third-level mathematics performance. The advancement made in the current study however distinguishes student success due to mathematics support engagement from students' other practices. While this may be unsurprising it is important to document nonetheless.

Short-term effect analyses and/or small sample size studies claiming positive effects of MSS on student mathematics performance are strengthened by such longitudinal studies as carried out here. Such studies bolster claims that MSS provision works for those students who avail of it, and can be used as evidence to encourage those who have yet to utilise its services. In addition, utilising a large data set involving dozens of university modules and thousands of students allows for generalisations that MSS works for academic modules of varying mathematical rigour (e.g. service versus specialist courses), and students of varying mathematical aptitudes, to be made. Thus this paper sets a baseline for examining trends among different student cohorts' engagement (or non-engagement) with their institution's MSS offering.

Student engagement with MSS, especially from those with lower mathematical attainment backgrounds, must continue to be encouraged so that all such students can gain these benefits. Planned future research will examine whether university students from non-traditional entry routes (e.g. mature, international, HEAR , DARE and QQI-FET) benefit (or lose out) disproportionally from MSS engagement (non-engagement) than their peers who enter university from more traditional routes.

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3 A scoping literature review of the impact and evaluation of mathematics and statistics support in higher education

Abstract

This paper presents the results of a systematic scoping literature review of higher education mathematics and statistics support (MSS) evaluation focusing on its impact on students. MSS is defined as any additional organised mathematical and/or statistical aid offered to higher education students outside of their regular programme of teaching by parties within the students' institution specifically assigned to give mathematical and/or statistical support. The objective of this review is to establish how MSS researchers investigate the effect of MSS on students and what that impact is. Based on a predefined protocol, five databases, the proceedings of eight conferences, two previous MSS literature reviews' reference lists, and six mathematics education or MSS networks' websites and reports were searched for publications in English since 2000. A two-round screening process resulted in 148 publications being included in the review which featured research from 12 countries. Ten formats of MSS, seven data sources (e.g., surveys), and 14 types of data (e.g., institution attainment, usage data) were identified with a range of analysis methods. Potential biases in MSS research were also considered. The synthesised results and discussion of this review include the mostly positive impact of MSS, issues in MSS evaluation research thus far, and rich opportunities for collaboration. The role MSS has and can play in mathematics education research is highlighted, looking towards the future of MSS evaluation research. Future directions suggested include more targeted systematic reviews, rigorous study design development, and greater cross-disciplinary and international collaboration.

3.1 Background

Mathematics and Statistics Support (MSS) is the provision of aid in mathematics, statistics, numeracy, and wider quantitative skills in higher education. It was predominantly created in response to what is referred to as the "mathematics problem" (Hawkes & Savage, 2000; Lawson et al., 2020). A large part of the mathematics problem is the more widely studied secondary-tertiary transition issue (Di Martino et al., 2023; Gueudet, 2008; Hochmuth et al., 2021; Thomas et al., 2015) where students struggle to adjust to the new norms of higher education mathematics and, in particular, are under-prepared to succeed. It also includes the issue of graduates being unprepared for the mathematical demands of the modern workplace. MSS seeks to support students underprepared for, and struggling with, the demand of higher education mathematics via provision of tutoring and mathematical resources. A common format of MSS is the Mathematics Support Centre (MSC), also known as tutoring or learning centres. Lawson and colleagues defined MSCs as facilities "offered to students (not necessarily of mathematics) which is in addition to their regular programme of teaching through lectures, tutorials, seminars, problems classes, personal tutorials, etc." (2003, p. 9). A broader definition of MSS includes MSCs and mathematical support provided by MSS provisions which are not necessarily held within the academic year (e.g., bridging courses) or based in a physical centre (e.g., videos, interactive applets, and worksheets). Teaching staff also provide support in and outside of scheduled class time, for example, Alcock and colleagues' e-proofs (Alcock et al., 2015). The definition of MSS used in this paper is any additional organised mathematical and/or statistical aid offered to higher education students, outside of their regular programme of teaching, by parties within the students' institution specifically assigned to give mathematical and/or statistical support.

A large part of existing MSS research details evaluation, in particular the impact that MSS has on the students who use it. Comprehensive reviews of various aspects of MSS in higher education appear in Matthews et al. (2013) and Lawson et al. (2020). Matthews et al. (2013) focus on the evaluation and impact of MSS, and provide a summary of 56 evaluation studies using predominantly qualitative analysis methods. Lawson et al. (2020) summarise 115 MSS articles in the period 2000-2019 under the headings of users/non-users, those who work in MSS, and evaluation. Building on Matthews et al. (2013), their evaluation section includes studies from 2013-2019. Both reviews highlight the move away from the necessary evaluation conducted by MSS provisions to secure funding to the optimisation of, and difficulties in, MSS evaluation, in addition to studies of both large and small scale indicating the value of MSS. The studies included in these reviews present results such as positive impact on student retention (e.g., O'Sullivan et al., 2014), student confidence (e.g., Dzator & Dzator, 2020) and academic performance (e.g., Jacob & Ní Fhloinn, 2019). This does not mean every MSS provision provides these benefits or indeed sets out to achieve these aims. Formats of MSS across institutions and countries can vary significantly from physical drop-in, appointments, and workshops to bridging courses, asynchronous online resources, and synchronous support via video conferencing – particularly prevalent in the years of pandemic-impacted learning. Research and evaluation methodologies are dependent on how MSS provisions operate, the data gathered by MSS provisions and what further data can be accessed (Matthews et al., 2013). The broad nature of MSS formats and evaluation methodologies prompted this systematic scoping review to establish how MSS is evaluated, the first review of its kind.

Previous literature reviews (Lawson et al., 2020; Matthews et al., 2013) were UK-based with some Irish, Australian, and German (only in Lawson et al., 2020) research also featured. However, MSS is now well established in higher education institutions (HEIs) in the USA (Mac an Bhaird & Thomas, 2023; Mills et al., 2022), UK (Ahmed et al., 2018; Grove et al., 2019), Ireland (Cronin et al., 2016), Australia (MacGillivray, 2009), Canada (Weatherby et al., 2018), and Germany (Liebendörfer et al., 2017; Schürmann et al., 2021), among other countries. Mills et al. (2022), in their survey of 75 mathematics tutoring centre directors in the USA, found 93.33% of respondents were performing evaluation of their centre; however, they note that published evaluation research in the USA has been sparse. Similarly, Weatherby et al. (2018) found that 88% of 62 English-speaking Canadian universities with mathematics departments had MSS provisions. However, they only reference two Canadian publications that include MSS (Dietsche, 2012; Faridhan et al., 2013). By using the broader definition of MSS outlined earlier and the systematic nature of a scoping review (Tricco et al., 2018), this paper will provide a more detailed picture of MSS evaluation studies published in English worldwide.

Systematic reviews are a defined research approach that provide the strongest evidence according to the hierarchy of evidence pyramid (NSW Government, 2020). This evidence is gathered via a formal process of identifying published empirical studies that fit pre-specified eligibility criteria defined to answer specific research questions. In particular, they feature an explicit, reproducible, pre-determined methodology, assessment of the validity of the findings by considering risk of bias, and a synthesis and/or meta-analysis of the results of included studies (Lasserson et al., 2022). There exist different types of systematic reviews; these include systematic (literature) reviews, scoping reviews, rapid reviews, narrative reviews, meta-analysis, umbrella reviews etc. The type of systematic review depends on the research question(s) and the nature of the studies to be synthesized. As systematic review results depend on the level of primary studies available, scoping reviews are the appropriate next step in MSS research to establish and summarise the level of research already conducted, building on the two previous literature reviews (Lawson et al., 2020; Matthews et al., 2013). Scoping reviews:

> may examine the extent (that is, size), range (variety), and nature (characteristics) of the evidence on a topic or question; determine the value of undertaking a systematic review; summarise findings from a body of knowledge that is heterogeneous in methods or

discipline; or identify gaps in the literature to aid the planning and commissioning of future research (Tricco et al., 2018, p. 1).

This paper presents a scoping review of MSS evaluation literature, meaning broad research questions and inclusion criteria will be used to find and examine relevant studies with a reproducible methodology. This scoping review will explore what data MSS provisions are gathering; how they are analysing that data; and how they use the results of that analysis; with a particular focus on the impact of MSS on students, both users and non-users. The review aims to use this information to identify areas of future MSS research. The four objectives listed in the review's protocol (Mullen et al., 2022a) align with the four research questions below, all focused on how MSS is evaluated:

1. When, where, and how are MSS evaluation studies published?
2. What are the different formats of MSS evaluated in these studies?
3. How and what data are collected for MSS evaluation, and is there potential for bias?
4. What are the analysis methods used in MSS evaluation and what results have been found?

Method and results sections now follow before a concluding discussion including future directions for MSS evaluation research and the role of MSS in mathematics education research more broadly.

3.2 Method

The review was conducted following the method outlined in the protocol (Mullen et al., 2022) which was based on the PRISMA scoping reviews checklist (Tricco et al., 2018). The updated version of this method is presented as minor changes were necessary during the course of the review. The first step, identifying the objectives of the review has been outlined in the introduction and the following steps of defining eligibility criteria and information sources, finding and screening of studies, and the data extracted from the included studies will now be outlined. The final step, data synthesis, will be presented in the results section.

3.2.1 Eligibility criteria

Studies were included using the following criteria: published in English from 1st January 2000; MSS featured had to be in addition to the students' regular programme of timetabled teaching and be formally organised by MSS providers within a HEI; and evaluation of the impact of MSS on students, whether users and/or non-users, using either statistical methods or qualitative analysis had to be present. Studies that used only usage statistics for evaluation were excluded. Reports of MSS evaluation at a single institution were excluded to prevent oversaturation however, reports containing evaluation of multiple MSS provisions (e.g., O'Sullivan et al., 2014) were included. Studies concerning predominantly tutor training, student-tutor interactions, or the design of MSS resources or provisions, and grey literature (except relevant reports) were excluded.

3.2.2 Information sources

In order to ensure broad coverage of MSS literature, which is still in early development, the information sources were varied. To ensure international coverage, colleagues in South Africa, Australia, New Zealand, Canada, the UK, the USA, Germany, and the Netherlands were contacted for relevant sources of national MSS literature and MSS terminology. Subsequently, these sources and terms were used to inform the search strategy. The sources searched included databases, conference proceedings, and national MSS websites. Databases searched were ACM Digital Library, SCOPUS, Web of Science, and Proquest Education Collection (which included PsychInfo, ERIC and Australian Educational database). Conference proceedings searched were:

- Congress of the European Society of Research in Mathematics Education (CERME)
- European Society for Engineering Education (SEFI)
- International Congress on Mathematical Education (ICME)
- International Network for Didactic Research in University Mathematics (INDRUM)
- Research in Undergraduate Mathematics Education (RUME)
- Southern Hemisphere Conference on the Teaching and Learning of Undergraduate Mathematics (Delta)
- International Group for the Psychology of Mathematics Education (PME)

National MSS/mathematics education websites searched were:

- Canadian Mathematics Education Study Group (CMESG)
- Centre for Research, Innovation and Coordination of Mathematics Teaching (MatRIC) – Norwegian centre for excellence in mathematics education
- First Year in Maths (FyiMaths) – Australia and New Zealand-based undergraduate mathematics education network
- Irish Mathematics Learning Support Network (IMLSN)
- Math Learning Centre Leaders (MLCL) – USA group of MSS leaders
- Scottish Maths Support Network
- Sigma Network for Excellence in Mathematics and Statistics Support (UK)

Additionally, the UK-based journal MSOR Connections, where MSS literature continues to be published, and the reference lists from the two previous MSS literature reviews, Lawson et al. (2020) and Matthews et al. (2013), were also searched.

3.2.3 Search strategy

The literature search was limited to publications in English with both quantitative and qualitative studies included. The search was limited to article title, abstract, keywords, and publication titles (dependent on the database). The exact search criteria and search string for each database is available in Appendix A. Each search string contained synonyms for higher education (e.g., university, third-level education) and a variety of terms for MSS (e.g., calculus center, math[ematics] support centre) with binary operators used so that every publication found had higher education and MSS terms. Both British and American English spellings were used.

The first database search took place on March 10th 2022, and the second (to ensure more recent studies had been included in the review) took place on November 9th 2022. At the time of the second search PyschInfo was no longer part of the Proquest Education Collection, therefore it was searched separately.

Conference proceedings, websites, MSOR Connections, and reference lists from Lawson et al. (2020) and Matthews et al. (2013), the "other sources", were searched from April to June 2022 initially and then any newly published conference proceedings or MSOR Connections publications, and the websites (for the second time) were searched in November 2022.

3.2.4 Selection process

Once duplicates were removed, a sample of 100 abstracts from the database search results was screened by all three researchers using the inclusion criteria. Any discrepancies between researchers' decisions were discussed with majority ruling. The remaining abstracts were then divided between researchers to be screened individually. Other sources were screened by abstract where possible with any duplicate studies found in the database search discounted. Due to the large number of conference proceedings and MSOR Connections articles, studies were first screened by title then abstract if available. Where no abstract was included, introductory paragraphs of a publication were screened. All pages of websites included in the search were reviewed to find studies that, if present, were screened by abstract.

The second round of screening reviewed full publications from both the database and other sources. This began with all researchers screening the same three studies, a change from the originally planned five studies due to time constraints. Any discrepancies in inclusion were discussed with the same approach taken as the first round of screening. Subsequently, the remaining publications were divided between researchers for individual screening. Reasons for excluding papers in the second round were recorded as part of the summary of the selection process using the PRISMA 2020 flow diagram (Page et al., 2021), Figure 3.1. The combined number of studies found in both database searches are shown in Figure 3.1 per database with the results of the separate PsycInfo search (second search only) in italics. The search process resulted in 136 evaluation studies from 148 publications.

3.2.5 Data collection process

Owing to the large volume of studies included, the studies were divided into those with an MSS evaluation focus and those where MSS evaluation was not the main focus of the study. The number of data items extracted was reduced for the latter set of studies. The (non-) evaluation focus was based upon studies' research questions/objectives, their title, and abstract/introduction if the former were not clear. The data extraction process was trialled by all three researchers with a pilot form for three publications from each set of studies. The results of this exercise were compared and discrepancies were resolved through discussion. The pilot form was updated to reflect these discussions and then used for the remaining studies.

3.2.6 Data items

The following items were collected from each evaluation focused study:

- Reference details: title, authors, year of publication, data source.
- Details of institution(s): name of institution(s) (if given), country of institution(s).
- MSS format: student population MSS available to, all services provided by MSS provision.
- Data collection: how, when, and what type of data were collected, how reliable the data collection method was, design of data collection (e.g., survey design) if applicable.
- Methodology: type of study (qualitative/quantitative/mixed-methods), whether research questions/aims/objectives were explicit, implied or not presented, data analysis method chosen.
- Results: outcomes of study for example, statistical significance, themes identified.
- Nature of research: funding source, ethics, conducted by MSS practitioners or researchers (internal or external).

"Type of institution", "location, size and design of MSS centre (if applicable)", and "design of MSS resources for example, bridging courses (if applicable)", were originally listed for collection but in the process of data extraction it was found that the type of institution was usually evident from the institution names, and that details of MSS centres and MSS resources design were not informative in understanding the study outcomes collected.

The reference details, details of institution(s), methodology, and results items listed previously were also collected from the non-evaluation focused studies. The items collected from the non-evaluation focused studies in the other categories were:

- MSS format: a description of the MSS services in the study.
- Data collection: how and what type of data was collected.

- Nature of research: ethics, conducted by MSS practitioners or researchers (internal or external).

3.2.7 Critical Appraisal of Individual Sources of Evidence

It was planned to evaluate the quality of the methodology and therefore the risk of bias in the studies included in the review using the Mixed Methods Appraisal Tool (MMAT) version 2018 (Hong et al., 2018). However, the first step of the MMAT tool requires explicit research questions, and as will be shown in the results, many included studies did not meet this criterion. As the quality evaluation is an optional part of a scoping review (Tricco et al., 2018), the researchers collectively decided to omit this element of the review as it can be done in future systematic literature reviews.

3.3 Results

Figure 3.1 shows the full search results, concluding in 148 publications being included in the review, representing 136 MSS evaluation studies (some studies resulted in multiple publications). These were divided into 66 evaluation focused publications (55 studies), and 82 publications (81 studies) where evaluation was not the main research objective of the publication. This was based on the research questions or aims of the publication where possible, otherwise on the title, abstract or researchers' reading of the paper. For example, a number of publications focused on the setting up of MSS provisions and provided some initial evaluation of the provision in the publication. In other publications, MSS evaluation was one question of a larger questionnaire or touched on briefly in an interview and therefore not the focus of the publications' results. The list of publications included in the review are available in Appendix B.

The following four results subsections answer each research question using the data extracted per publication for the first subsection and per study for the other three subsections. Where possible, results from all included studies will be presented, however the evaluation focused studies will take priority in the reporting of results. Details of each data item collected for the 55 evaluation focused studies are available in Tables C1 and C2 of Appendix C.

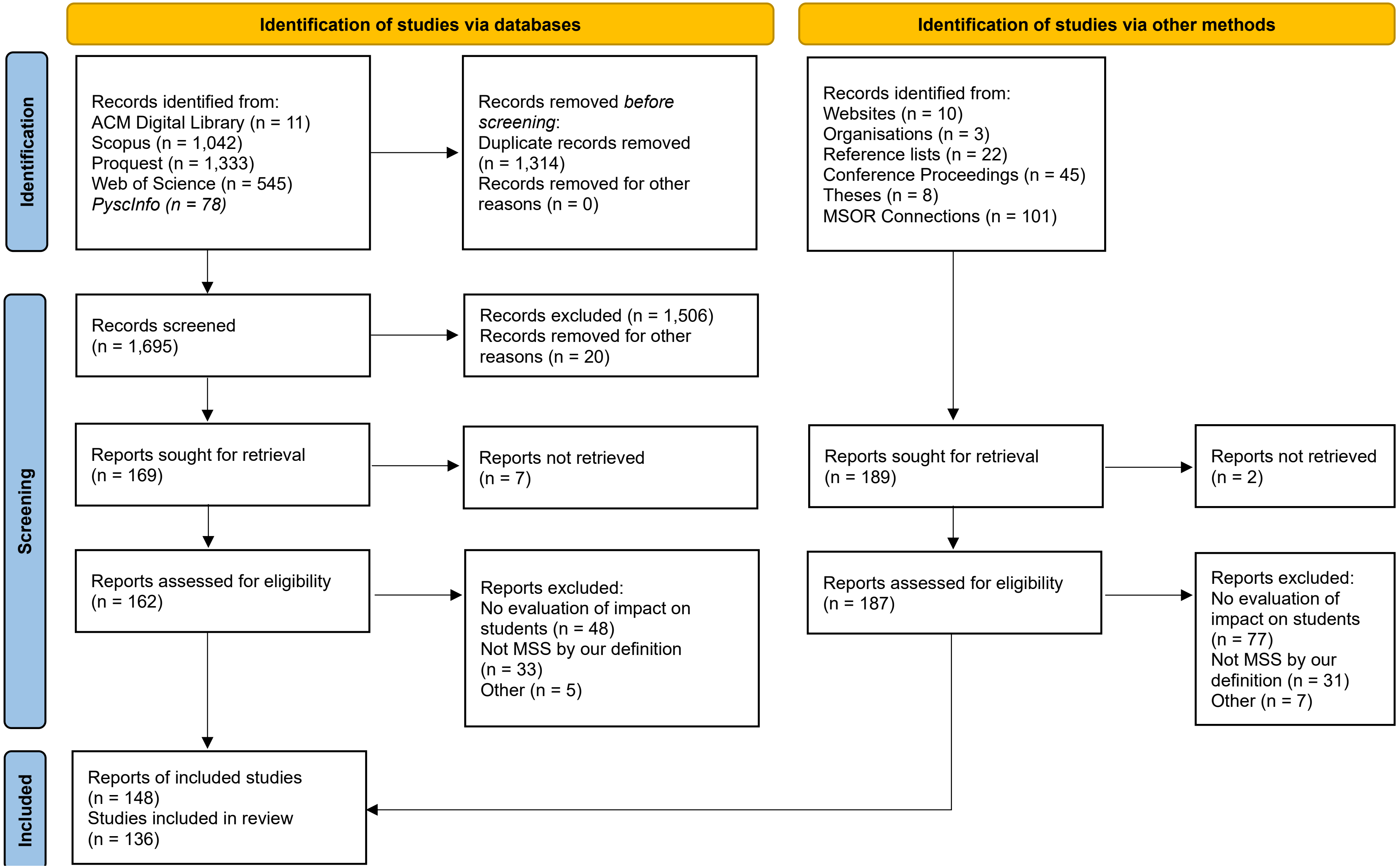

Figure 3.1: PRISMA flow diagram (Page et al., 2021) showing the identification, screening, and inclusion of publications found through databases and other sources.

3.3.1 When, where, and how of MSS research publication

The search included all publications from January 1st 2000 to November 9th 2022[2]. The 148 included publications; 65 journal articles, 31 conference proceedings, 40 MSOR Connections or CETL-MSOR publications (grouped under "MSOR Connections")[3], six theses, and six books/reports, graphed in Figure 3.2 show the variety of MSS evaluation publications over the past 23 years.

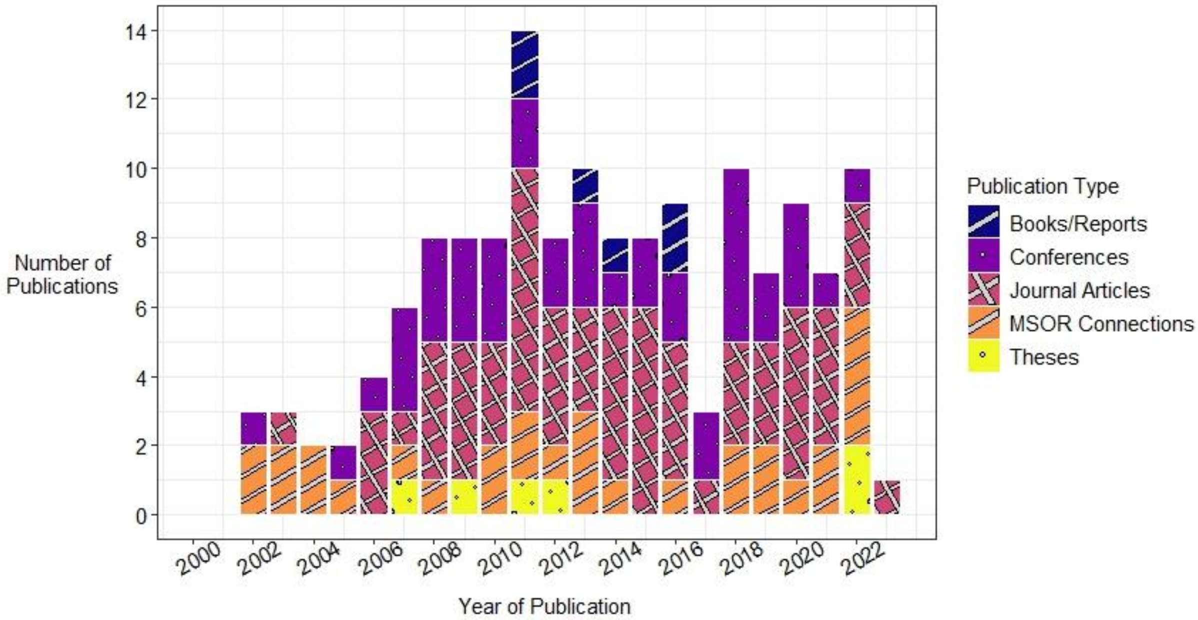

Figure 3.2: The number of included publications per year grouped by publication type.

Figure 3.3 displays the countries in which the included publications were conducted per year. The "Multiple" group contains the four publications that were a cross-collaboration from multiple countries, namely two papers that were a collaboration between Irish and Australian researchers; a paper from an Australian, Irish, and British collaboration; and a report on Irish and Northern Irish MSS. Countries only represented once, namely Canada, Czech Republic, Finland, Italy, Netherlands, and Slovakia, and South Africa which has two included publications, are grouped together in Figure 3.3 under "Other". Finally, two publications did not identify their country of origin (Not Stated).

[2] The year of publication for all references was updated during the writing of this paper to reflect the publications' official references. Subsequently, the publication by Johns et al. (2023), while available since 2021 online and thereby found in the search, falls outside the official search years.

[3] As later CETL-MSOR proceedings were published as *MSOR Connections* special issues, CETL-MSOR proceeding papers are grouped with *MSOR Connections* papers instead of the other conference proceedings papers.

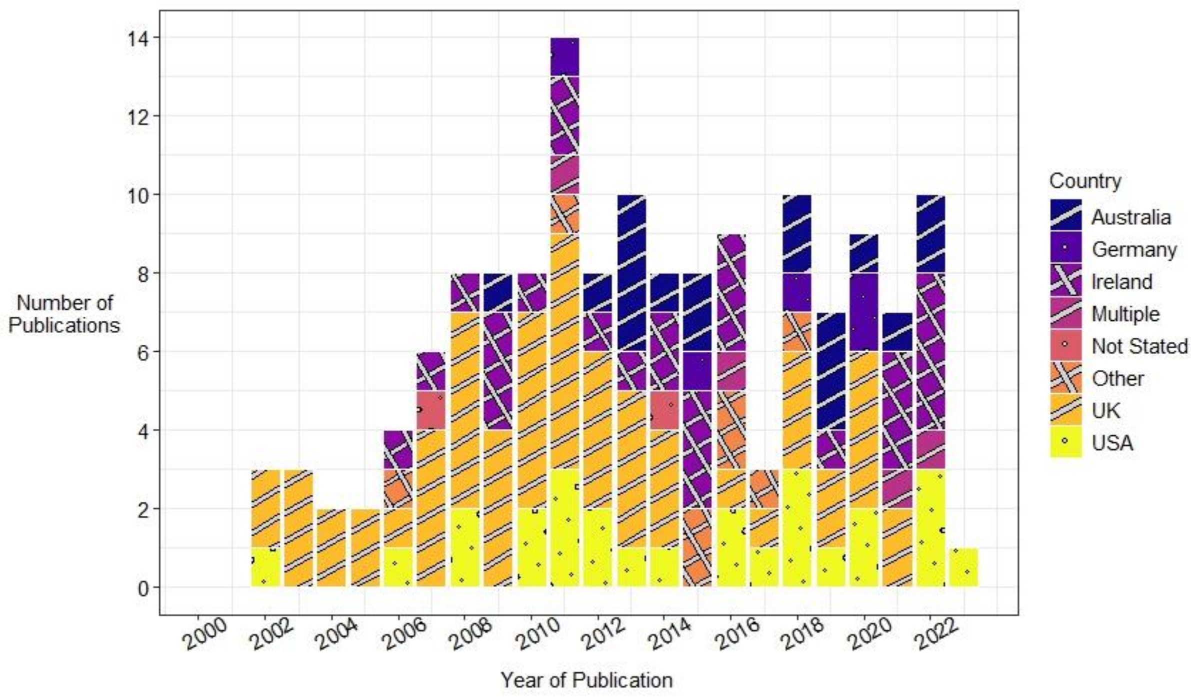

Figure 3.3: The number of included publications per year grouped by country.

Table 3.1 presents counts of how explicitly the research questions or aims and ethics details were stated in the 66 evaluation focused and 82 non-evaluation focused publications. Funding details were only provided in 10 of the evaluation focused publications. The authors of the included publications were mainly based in the institution at the focus of their study. Seven evaluation focused and three non-evaluation focused publications had exclusively researchers external to the institution while 14 evaluation focused and 18 non-evaluation focused publications were written by a mix of internal and external researchers. Four evaluation focused and four non-evaluation focused publications did not provide enough information to determine the status of the researchers.

Table 3.1: The number of publications in which research questions or aims, and ethical approval details were stated explicitly and the clarity of the statement.

	Research questions or aims		**Ethical approval details**	
	Evaluation	Non-evaluation	Evaluation	Non-evaluation
Explicit	44	29	18	11
Implied/Unclear	18	29	3	1
Not stated	4	24	45	70

3.3.2 MSS formats

The range of MSS formats described in the 136 included studies can be seen in Figure 3.4, presented as a heatmap by country group. For example, of the 15 studies conducted in Australia, nine or 66.67% of the studies featured online resources. Note that 53 studies evaluate more than one MSS format.

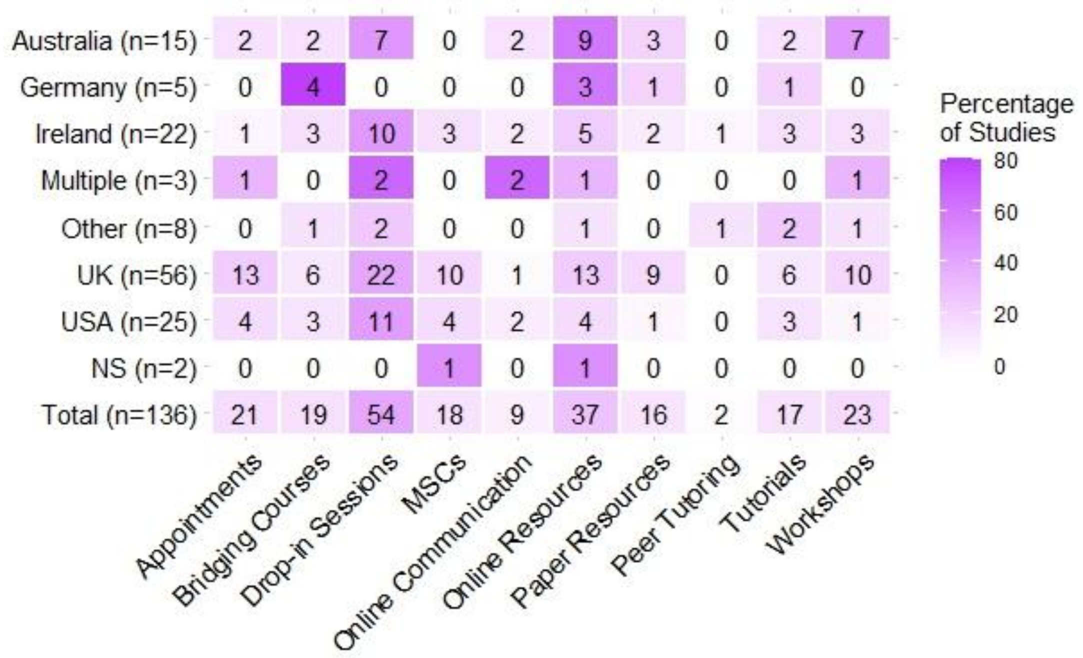

Figure 3.4: Heatmap of MSS formats by country group in the 136 included studies.

Popular in the majority of countries, drop-in sessions were the most frequently discussed format of MSS (n=54). The 18 studies where the MSS was described as an MSC may also involve drop-in support. Appointments, or timetabled one-to-one or small group support can also be part of a MSC's services.

Larger group MSS sessions, taking place concurrent with timetabled teaching, fell into two formats, workshops and tutorials. Workshops were usually designed around active learning while descriptions of MSS tutorials indicated a more teacher or tutor-led class. Bridging courses also involved larger groups of students but generally occurred before timetabled teaching began.

Online communication groups all types of MSS provided through tutors being online either synchronously with students, for example in a video call, or asynchronously, for example in discussion boards. This MSS format is increasingly popular since COVID-19 first introduced restrictions on in-person learning. Online resources, where MSS is provided through videos, worksheets, or other materials placed online, have been evaluated more frequently with at least one study per year since 2007 (excluding 2018). Paper resources have also been evaluated throughout the two decades, though to a lesser extent, and often with other types of MSS.

Peer tutoring was identified in only two studies, Maitland and Lemmer (2011) and Parkinson (2009). Both studies feature more experienced undergraduate students tutoring those in need of support and thus are different enough from the other MSS formats to warrant a separate category.

The student population studied was extracted for all the evaluation focused studies. Note this was not necessarily the same as the population that MSS was available to in the institution(s), for example, first-year students were studied but second-year students could also access MSS. Notably, 23 of the 55 populations studied were first-year students (42%); highlighting the role of MSS in the transition to higher education. Seven studies focused on students in developmental or foundational mathematics classes and 10 studies aimed to evaluate MSS for all users. Many publications focused on students from one degree or school with 13 studies researching students studying a form of engineering.

3.3.3 Data collection

The data source and type of data collected, both of which were categorised, were collected from all studies while the sample size and data information were extracted from evaluation focused studies only. Data information, a subjective item as no explicit categories were identified by the researchers, recorded what information was (not) provided in the publications with regard to study design and had the potential to bias results. For example, if survey response rates were (not) provided this was noted under data information.

Seven different data source categories were identified. The most frequent data source was surveys (*n*=81). Four of those surveys used adapted versions of previously used questionnaires including 1) the Mathematics Self-efficacy Scale (Betz & Hackett, 1993) in Johnson and O'Keeffe (2016); 2) the Mathematics Self-Efficacy and Anxiety Questionnaire (Deutsch, 2017) in Johnson (2022); 3) the Inventory of Mathematics Attitude, Experience, and Self-awareness instrument (Klinger, 2008) and the IMLSN evaluation survey (O'Sullivan et al., 2014) in Carroll (2011) and Carroll and Gill (2012); and, 4) the attitude questions from Carroll and Gill (2012) were used in Dzator and Dzator (2020). The second most popular source of data was from institutional or MSS records (*n*=74). The other data source categories identified (and the number of studies that used them) were focus groups (*n*=8), interviews (*n*=15), pre- and post-skills assessments (*n*=14), and other (*n*=19); which includes various forms of written feedback not gathered through a survey instrument, and researchers' observations or field notes. Nine studies, all non-evaluation focused, did not provide details of their data sources.

Comparing the different MSS formats studied and the data sources used to study them, only the two most popular data sources, surveys, and institutional/MSS records, have been used to evaluate every MSS format. Investigating the others, none of the bridging course studies used interviews or focus groups, and only one study involving MSS appointments used a pre- and post-skills assessment as a data source. Table D1 in Appendix D presents a full comparison of the MSS formats and data sources. Turning to type of data used for evaluation, Table 3.2 presents the 14 data types identified, their definition and the number of studies they were in. There were some formats that did not collect some data types. For example, pre-institutional attainment was not considered when evaluating online communication or tutorials. Broadly, however, the different MSS formats did not collect different data types.

Table 3.2: Names and definitions of the data types collected in the 136 included studies, and the number of studies they were present in.

Data Type Name	Data Type Definition	Number of Studies
Usage	How frequently or not students used the MSS available	95
Institution attainment	Students' grades, marks, grade point average, or pass rates in higher education	68
Qual	Qualitative data from students	67
Diagnostic	Results of a diagnostic test(s)	38
Likert	Scaled data usually relating to helpfulness or usefulness	32
Course	Details of students' degrees or course/module information	30
Pre-institution attainment	Results or grades from students' previous education	29
Affective	Measuring issues like mathematics self-efficacy, mathematics anxiety, or other psychological/mental aspects of mathematics	22
Demographics	Data relating to age, gender, or other personal information	20
Retention	Data around students attrition in higher education	15
Qual – tutor/faculty	Qualitative data from non-students (mainly staff)	13
MSC features	MSC characteristics like number of tutors available	9
Other	Information not covered by the other data types	2
Not stated	Type of data collected was not described	2

Most evaluation focused studies had different potential biases or missing information recorded under "Data Information" which can be read in Table C2 in Appendix C. Identifiable trends include a lack of clarity around the source of data, for example, whether it was student reported or from institutional records; unclear sampling strategies used to recruit participants, and a range of different response rates (where they were recorded). Some authors, for example Wilkins (2015), discussed problems and sources of bias with respect to their data collection, others were less explicit.

3.3.4 Analysis methods and results

The 136 included studies present a wide variety of analysis methods, both quantitative and qualitative, and correspondingly a broad range of results. Table 3.2 shows the majority of studies had some quantitative data, for example, 95 used quantitative usage data, and thus most (n=97) presented some form of descriptive statistics. Some studies did no further analysis but most quantitative studies presented either hypothesis tests results, correlation analysis, and/or regression analysis. The most frequently presented hypothesis tests were t-tests (n=22), chi-squared tests (n=17), and analysis of variance (ANOVA) (n=13). These were usually used to find the differences between MSS users and non-users or in some studies the differences between types of MSS users (usually visit frequency or demographics). Further rigorous analysis connected with these tests, for example p-value correction for multiple tests and Tukey post-hoc test for ANOVA, was not always discussed. Correlation analysis was employed in 15 studies to study the association between MSS use and different measures of student impact, most commonly institution attainment. Simple linear (n=8), multiple linear (n=7) and forms of logistic (n=5) regression were also used in the evaluation of MSS student impact usually aiming to model institution attainment based on MSS use, and in the case of the multivariable models on other factors like pre-institution attainment, diagnostic results and/or demographics. Byerley et al. (2018) included the most variables (16) in their multinomial logistic regression model while Offenholley (2014) used seven variables. The other studies that used regression equations considered between two and five variables. All statistical methods used were frequentist methods as opposed to Bayesian methods.

Qualitative data was collected in 67 of the included studies (the 13 studies with qualitative data from staff also contained qualitative data from students). The most named and used form of analysis was thematic analysis of various forms with 5 of the 14 studies using thematic analysis referencing Braun and Clarke (2006) specifically. Other qualitative analysis methods used were categorisation and general inductive analysis. However, in 34 of all the included studies no qualitative analysis method was described despite qualitative data and results being presented. Furthermore, 13 of the non-evaluation focused studies did not describe an analysis method.

The majority of the broad range of results published about MSS evaluation show a positive impact on students but not all did. Highlights of the 55 evaluation focused studies include 18 studies finding MSS had a statistically significant positive effect on grades, 15 studies reporting higher pass rates for MSS users, and 13 studies recording a gain in students' confidence due to MSS. Six studies noted no difference in grades/pass rates between MSS users and non-users including Offenholley (2014) who compared students from the same course who had access to online MSS and used it, those who did not use it, and those that did not have access, though only a small number used the MSS. Halcrow and Iiams (2011) compared students from the same course who were given 5% of their grade for visiting the MSC weekly versus those who were just told about the MSC and found no difference in grades. Some studies, for example, Patel (2011), found statistically significant positive and negative effects of MSS for different cohorts of students. Each study's results speak to the specific format of MSS in place, the students being studied and the research design, all presented in Table C2 in Appendix C. The results from the other 81 studies that were non-evaluation focused were less specific although many studies presented forms of student feedback that were generally positive. The helpfulness or usefulness of MSS was usually highlighted in this qualitative data and similar positive feedback are also highlighted in some of the evaluation focused studies.

3.4 Discussion

3.4.1 When, where, and how of MSS research publication

The inclusion of 148 publications reporting 136 studies from 12 countries in this scoping review shows the geographical spread of MSS and growth of the accompanying evaluation research over the past two decades. Where there is MSS, there is usually evaluation, and while not all evaluation published satisfies the inclusion criteria of this review, the research that does highlights the role MSS plays in institutions. The results of the review revealed MSS evaluation literature exists in more countries than in previously published reviews (Lawson et al., 2020; Matthews et al., 2013); highlighting the advantages of a scoping review. Further publications not included in this review but found through the search strategy show MSS taking place in countries other than those most frequently published. For example, a paper about MSS in Hong Kong (Chan & Lee, 2012) was excluded. It should be highlighted that there could be further countries with MSS publications that were not found owing to this review's criteria, that is, all publications had to be in English. The issue of underrepresentation of certain geographical areas in mathematics education publications (Di Martino et al., 2023) must also be noted. More reports of how MSS is provided and evaluated in the countries not included or only included in small numbers in the review would be of great interest to the MSS community.

The reason behind extracting the "nature of research" data items, was to investigate the way research is conducted which informs the strength of MSS literature. Thus, features of high-quality research (Belcher et al., 2016) reporting such as the statement of research questions and providing ethical details were noted to track the development of MSS literature. These features also affect the suitability of publications for inclusion in systematic reviews as, for example, critical appraisal tools such as the MMAT (Hong et al., 2018), considered for this review, require explicit research questions. Results of this data extraction were somewhat concerning with only 73 (of 148) publications stating research questions or aims and 29 providing ethical information - all publications except one dealt with student data in some capacity. However, as highlighted by the small amount of evaluation literature in the early 2000s, MSS is a relatively nascent research area. The inclusion of publications other than journal articles in this review was purposeful as other publication sources such as conference proceedings may be more accessible for new MSS researchers or staff who provide MSS but do not have research responsibilities. The majority of MSS research is carried out by practitioners immersed in running their institution's MSS provision (100 publications from internal researchers only). Research may not be a part of their role (Grove et al., 2019), or they may not have the funding for it (only 10 of the 66 evaluation focused publications noted funding). The results of collaborative, funded research has and will develop MSS research. Examples included are Byerly and colleagues who, benefiting from National Science Foundation funding (Mills et al., 2022), authored a series of publications (Byerly et al., 2020; Byerley et al., 2024; Johns et al., 2023) evaluating and comparing 10 USA MSCs with various results. For example, only six of the MSCs had a positive change in grade per one visit based on multiple regression (Byerly et al., 2020). Also, the report from O'Sullivan et al. (2014) provided student-reported results on retention and MSS use on a scale not seen elsewhere. Surveying 1,633 students from nine institutions, 587 of whom had used MSS, they found that 62.7% of 110 students who had both considered leaving higher education and had used MSS were influenced to stay by MSS.

3.4.2 MSS formats

MSS format trends for countries are confirmed, for example, the case of Germany's use of bridging courses over other formats. Liebendörfer et al. (2022) explain that German MSS developed owing to a rapid increase in higher education participation rates and subsequent dropout rates, particularly evident in mathematics where insufficient prior knowledge is a factor. Bridging courses, concentrated on reinforcing prior mathematical knowledge, are the primary MSS format in Germany, although other formats in Germany are starting to be evaluated (Liebendörfer et al., 2022). The variety of MSS formats in the UK, Australia, Ireland and the USA is a result of their respective educational system. In the UK, Lawson and Croft (2021) explain MSS was set up over 25 years ago as a short-term solution to a much larger problem – students entering higher education unprepared for the demands of university mathematics. Owing to a lack of compulsory secondary-level mathematics in the UK and Australia, students may not have studied mathematics, or a high level of mathematics in upper secondary school, thus MSS in a variety of formats was set up in both countries (Lawson & Croft, 2021; MacGillivray, 2009). Interestingly, the same variety of MSS formats is present in Irish studies though the vast majority of Irish students study mathematics throughout secondary school as a mandatory subject for higher education. However Irish students' mathematical attainment is of ongoing concern (Gill et al., 2010; O'Meara et al., 2020), hence MSS is similarly well-established. The length of time MSS has had to develop aligns with variety in formats. Higher education in the USA lends itself to a variety of MSS formats given the large numbers of HEIs, varying school curricula and no national curriculum or examinations. Mills et al. (2022) explain that general education courses, including mathematics, are mandatory and thus the USA HEIs have a wide array of mathematics students, low pass rates in entry level mathematics courses, and well-established MSS. The small number of longitudinal evaluation studies and other literature about the development of MSS (Ahmed et al., 2018; Croft et al., 2022; Cronin et al., 2016; Grove et al., 2019; MacGillivray, 2009; Mills et al., 2022) point to how established MSS is in the UK, Ireland, Australia, and the USA, and the largely positive evaluation results explains why. For countries with fewer publications, but still positive evaluations, the continued provision of MSS is expected, for example a recent German-British collaboration notes the current expansion of German MSS (Gilbert et al., 2023).

3.4.3 Data collection

In many publications, the study design was unclear. Details such as questionnaire design, sampling strategy, and exact sources of records were not presented. Response rates, when provided, were often low, in line with other education research. Finally, the lack of detail in reporting qualitative analysis methods, and in some cases no methodological details, in publications implies an unsatisfying answer to our third research question. Reasons for this may be less stringent publication rules for most of the sources of MSS evaluation literature or the constraints on the researchers themselves, as discussed previously. There are many natural constraints to conducting research on students, and their data, that affect data collection particularly in MSS research as MSS participation is voluntary and therefore self-selection effects appear. Studies where quantitative data from existing MSS or institutional records were used usually had clearer data collection strategies. However, they could only consider a small number of variables in examining the impact of MSS, for example, Rylands and Shearman, (2018) and Rickard and Mills (2018). On the other hand, studies collecting qualitative data rely on student participation which is difficult to achieve especially in an unbiased manner. Wilkins (2015) provided a candid report of the problems with their MSS evaluation study using student surveys. Duranczyk et al. (2006) had fewer issues by adding questions to a larger school-wide survey. Explicit reporting of evaluative issues will allow for greater understanding and comparison of results which is necessary for systematic reviews. As outlined in Section 1, systematic reviews provide the highest level of evidence (NSW Government, 2020) and would be an important development in MSS research.

3.4.4 Analysis methods and results

The variation in analysis methods and results in MSS evaluation research is the outcome of many researchers in a relatively new research area evaluating their own unique MSS provisions. Based on the lack of funding disclosed, MSS research resources are sparse. There are many challenges to MSS evaluation, in particular the issue of self-selection bias and how to demonstrate causal relationships. Developments in evaluation research include use of statistical methods to analyse associations between grades and MSS usage moving from chi-squared tests and similar, (e.g., Mac An Bhaird et al., 2009), to building regression models involving MSS variables (e.g., Byerley et al. 2018). Byerley et al. (2018) consider the issues of self-selection bias and causation versus correlation, and point out studies demonstrating causal relationships require random assignment to the treatment condition, which is often not possible or ethical with MSS. Instead, self-selected users and non-users are compared. As noted in the results, Offenholley (2014) gave eight of 112 sections of

Elementary Algebra students access to online MSS and compared the results of users, non-users, and those without access finding MSS had no impact on grades but there was low MSS uptake. Studies like these may be more possible within the USA higher education system where one course is taught across many sections, though it would be difficult to evaluate MSCs in this way. However, in other higher educational systems, like Ireland, students are separated into mathematical courses by degree and usually taught as one class. Providing access to MSS for some students and not others in one class could be considered unethical. Thus, the issue of self-selection bias affects the results of almost all studies included in this review.

The diversity in answers to the second, third, and fourth research questions, namely 10 formats of MSS, seven data sources, 14 data types, over 40 analysis methods and corresponding results all from 136 studies, is extensive. This scoping review presents a broad overview of MSS evaluation research published in English worldwide with the objective of establishing how MSS researchers are investigating the impact of MSS on students and what that impact is. While it is possible to extrapolate the positive impacts of MSS, particularly on students' grades, it is impossible to reach definitive conclusions about this impact due to lack of uniformity and robustness in data collection and analysis. This is not unexpected due to the many factors impacting MSS research previously discussed but does indicate further development of MSS evaluation research is desirable. The scoping review definition previously presented, suggests a review can "summarise findings from a body of knowledge that is heterogeneous in methods or discipline" (Tricco et al., 2018, p. 1). Given there are no standard methodologies or research metrics yet established in the discipline of MSS learning impact the results of this review show that the lack of heterogeneity in methodologies used make it difficult to compare and contrast studies about purported effect of MSS. However, there is a trend in MSS literature evolving from scholarship in the early years to more rigorous research in recent years and this is very welcome.

3.5 Future directions for MSS evaluation research

Development of more rigorous study design is a necessary next step in MSS evaluation. Self-selection bias, particularly when research relies on student-reported data, must be considered and addressed whenever evaluating MSS. Finding a causal link between MSS and aspects of students' mathematical experiences is still a work in progress due to evaluation methods used thus far not fully incorporating self-selection bias. Herzog (2014), included in this review, aimed to demonstrate propensity score matching, which incorporates self-selection bias, with a MSC evaluation as an example case study, and found positive results yet this method was not used again until Büchele and Schürmann (2023). Büchele and Schürmann (2023), using propensity score matching and difference-in-differences methods which control for students' self-selection, have taken a step forward in this area. However, as they admit, there is a need for further development and an increase in study scale of this type of evaluation as they only studied a course-specific MSC open one afternoon a week. Hopefully this review will bring greater awareness and use of these methods to benefit MSS evaluation research. Other elements of study design, for example, ensuring representative responses to surveys and well-considered missing data strategies could also be developed further. Who is and is not using MSS, and who is and is not participating in MSS evaluation research must both be considered to inform rigorous evaluation research.

The findings of this review also highlight how MSS evaluation may be studied further. More multi-institutional and international collaborations would be welcome as only 16 multi-institutional studies and three international collaborations were found in this review, yet they contained noteworthy results. There are rich opportunities for collaboration in MSS research not only between MSS practitioners but also mathematics education researchers, statisticians, methodological researchers, and those who provide STEM education at university. Collaboration across various support services available in HEIs would also be welcome as students do not necessarily access these services in isolation. One approach to furthering MSS collaboration and data collection would be by using the same instrument in multiple institutions much like how Dzator and Dzator (2020) used items from Carroll and Gill's (2012) research instrument. Validation of survey instruments (e.g., exploratory and confirmatory factor analysis) built for general mathematics education research (e.g., mathematics anxiety scales) in MSS settings would also be valuable to the MSS research community. As discussed in Howard et al. (2023), another approach for furthering collaboration, and MSS research more generally, would be to have standardised terminology for MSS that is internationally used. It is recommended that all future MSS research includes the key terms "mathematics and statistics support" and "higher education".

Systematic reviews with more stringent eligibility criteria and specific research questions about aspects of MSS, are a credible next step in combining MSS research for greater generalisation of results. This review indicates drop-in MSS, which featured in 54 studies, would be the most viable format of MSS to examine via a systematic review and/or meta-analysis as such reviews benefit from a greater number of studies. Additionally, meta-analysis would require similar populations and outcome measures to have been used in the included studies. In general, while a statistical comparison of MSS evaluation results would advance the field without the need for further resource-heavy data collection, the results of this review indicate that this process may be hindered by missing reporting features. Also, changes in students' MSS usage patterns during and after the pandemic (discussed in Mullen et al., 2021; Mullen et al., 2022; Gilbert et al. (2023); and Johns & Mills (2021)) must be accounted for. Further publications of evaluations of drop-in MSS and (or versus) other MSS formats post-pandemic would improve the relevance of results of a systematic review of MSS evaluation.

3.6 Conclusion

In conclusion, this scoping review highlights the variety of MSS evaluation work already published and the great potential for more work in this area. The research included in this review indicates the positive impact MSS can have on students but also the need for more rigorous methodological evaluation of this effect. There is a large international group of MSS researchers and practitioners who can build a comprehensive research agenda around MSS evaluation and other important aspects of MSS research. Greater understanding of students' higher education mathematics experience is needed to continue attempts at solving the mathematics problem and MSS research and evaluation are key pieces of the puzzle.

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4 Mathematics is different: student and tutor perspectives from Ireland and Australia on online support during COVID-19

Abstract

From March 2020, the Mathematics Support Centre at University College Dublin, Ireland, and the Mathematics Education Support Hub at Western Sydney University, Australia, moved wholly online and have largely remained so to the point of writing (August 2021). The dramatic and swift changes brought on by COVID-19, in particular to fully online modes of teaching and learning including mathematics and statistics support (MSS), have presented students and tutors with a host of new opportunities for thinking and working. This study aims to gain insight both from students and tutors about their experience of wholly online learning and tutoring in the COVID-19 era. In this sense, it represents a ‘perspectives’ study, the idea being that before examining specific aspects of this experience, it would be best to know what the issues are. Employing a qualitative analysis framework of 23 one-on-one interview transcripts with tutors and students from both institutions in Australia and Ireland, five themes were identified as central to the shared experiences and perspectives of tutors and students. This paper discusses three of these themes in relation to the new normal with the intention of supporting MSS practitioners, researchers and students going forward. The themes describe the usage of online support, how mathematics is different and the future of online MSS.

4.1 Introduction

Mathematics and statistics support (MSS) is complementary to regular timetabled teaching activities such as formal lectures, tutorials, problem solving classes and laboratories. In many countries, MSS has come about as a response to what is commonly known as the 'mathematics problem'. This refers to a complex combination of issues including the under preparedness of incoming undergraduate students from secondary school, the growing diversity in mathematical backgrounds of students due to widening participation agendas and the ever-increasing requirement of employers for graduates to have quantitative reasoning skills. Extensive literature reviews of MSS, including the evolving "mathematics problem" spanning over 25 years of scholarship, have been conducted by Matthews et al. (2013) and Lawson et al. (2020), with country specific reports of the problem and MSS in Australia (Barrington & Brown, 2014; Productivity Commission, 2019), Ireland (Gill et al., 2010; MacCraith, 2016), the UK (Grove et al., 2020), Germany (Schürmann et al., 2021) and the USA (Mills et al., 2020), among other nations. While in-person MSS provision has become the norm, its online equivalent has seen slower take up in the on-campus traditional model of higher education. The technology to provide MSS online has existed for some time but it was not until March 2020 that the COVID-19 pandemic forced staff and students to vacate campuses and to embrace fully online learning and teaching. Prior to this, there had been limited research investigating the online offering of MSS (Cronin & Breen, 2015; Mac an Bhaird et al., 2021; Pettigrew & Shearman, 2013), and until recently the consensus from both students and tutors was that online MSS cannot replace the quality experience of the in-person context. Now that online MSS has been experienced by many for a considerable amount of time, there is significant interest in the evaluation of such support, partly to inform decisions about its use in the future. With this in mind, this paper aims to address the following research question:

What are the issues common to an Australian and an Irish university, from both the student and tutor perspective during the COVID-19 era, pertaining to the use and future of online MSS?

4.2 Literature review

4.2.1 Mathematics and statistics support in Australia and Ireland

In Australia, MSS goes back at least as far as 1973, with dedicated centres in universities created to provide MSS appearing in, and possibly predating, 1984 (Dzator & Dzator, 2018; MacGillivray, 2009). By 2007, some form of MSS was provided by 32 of Australia's 39 universities (MacGillivray, 2009). There are a variety of documented ways in which MSS can benefit students, for example, better grades, increased confidence and greater retention. In Australia, there are many examples from the literature reporting on such benefits to students from MSS engagement including

Rylands & Shearman (2018), Jackson (2013), Jackson & Johnson (2020), Hillock & Khan (2019), MacGillivray (2009) and Dzator & Dzator (2018).

MSS was established as early as 1999 in the Republic of Ireland (Cronin et al., 2016) with the first support centre set up in 2001 at the University of Limerick. As of 2016, there was MSS of some description in almost all higher education institutions on the island of Ireland (Cronin et al., 2016). Again, these services were established in response to variants of the 'mathematics problem' mentioned earlier. In Ireland, there have been articles published on the positive impact of MSS: on students' grades (Jacob & Ní Fhloinn, 2018), student retention (O'Sullivan et al., 2014) and teaching practice (Cronin et al., 2019; Cronin & Meehan, 2020).

4.2.2 Online mathematics support

A survey of MSS in Ireland up to 2015 (Cronin et al., 2016) found that of 30 institutions, 25 offered MSS. Only 12 of these offered some online support (here online included advertising and links to resources) and only one offered synchronous interactions with a tutor. A 2018 UK and Ireland survey (Mac an Bhaird et al., 2021) of institutions' online MSS presence received a response rate of approximately 28% from institutions known to have provided MSS at that time. Some 20 of 33 respondents stated that they had offered synchronous MSS sessions. In general, this virtual support was not taken up by students regularly and the technology was rated poorly in terms of student learning, synchronisation and wi-fi connectivity. Barriers to providing an online MSS presence included staffing issues, technology, funding, student awareness of ICT and preference (practitioners) for face-to-face tuition.

There were a number of surveys, both of MSS practitioners (Hodds, 2020; Johns & Mills, 2021) and undergraduate mathematics students (Meehan & Howard, 2020), conducted within the initial months of the pandemic-enforced changes to higher education in mid 2020. Hodds (2020) describes the differences in pre- and post-pandemic MSS offerings from 78 higher education institutions around the world including 19 outside the UK. This report details a significant decrease in MSS student engagement when the move to fully online MSS occurred. Johns & Mills (2021) discuss best practice for online MSS and offer recommendations for practitioners based on the views of 28 MSS leaders in the USA. The undergraduate student perspective of the affordances and constraints of online mathematics learning during the initial COVID period, in addition to a set of recommendations for lecturers going forward, is reported in Meehan & Howard (2020).

4.2.3 Online teaching and learning

While there has been little research reported on online MSS, there is a large body of research into online learning, some of which includes online mathematics. It is now timely, with students being forced to study online, to consider the body of literature about online learning in order to improve online MSS.

Since the emergence of online education in the early to mid 1990s, a vast body of research has arisen to examine its effectiveness and explore its potential (Martin et al., 2020). Separating the studies that address broad questions of the value and purpose of online education from those that seek to unearth nuanced, contextual and discipline-specific issues is an important, though infrequently considered, task (Paechter & Maier, 2010; Protopsaltis & Baumi, 2019; Smith et al., 2008; Trenholm, 2013; Trenholm et al., 2019). This has particular implications for research whose aim is to investigate online teaching and learning approaches in mathematics, a discipline that is special across a range of dimensions, including pedagogy, learning psychology, use of abstraction, symbolic language, idiomatic written and notational conventions and application of 'sequentially-acquired' conceptual knowledge (Smith et al., 2008; Trenholm et al., 2019).

Much attention is given in the literature to the benefits of online education, for example, flexibility, personalization, convenience, expanded access, time efficiency, affordance of anonymity, increased learning environment amenity and protection from distractions. However, critical appraisals of its capacity to deliver high-quality learning are rare (Danielson et al., 2014; Figlio, 2016; Jaggars, 2014; Protopsaltis & Baumi, 2019; Trenholm, 2013; Trenholm et al., 2016). This is regrettable as the distinction has special relevance to the debate about the comparative effectiveness of online and face-to-face approaches to teaching and learning. Moreover, the debate is complicated by evidence that the advantages and academic rewards of online learning vary depending on a variety of factors. For example, socio- economically disadvantaged students suffer substandard learning outcomes when studying online. They are also ill-equipped to motivate themselves, regulate, organize, structure or direct their own online learning and struggle with time management and developing (or activating) independent learning skills (same references as before) (Barshay, 2015; Cavanaugh & Jacquemin, 2015; Otter et al., 2013; Protopsaltis & Baumi, 2019; Xu & Jaggars, 2013, 2014).

The challenges facing teachers working in online environments, many of whom have been forced due to COVID-19 to negotiate exclusively digitally mediated relationships with their students, are profound. Some researchers suggest that, no matter what the medium, pedagogy is preeminent (Bernard et al., 2004; Meehan & Howard, 2020; O'Neill et al., 2004). Learning frameworks and guiding pedagogical principles inform tutors' practice and these need to be adjusted to accommodate online relations with students. Concerns about how to recapture the immediacy of "short-cycle" interactions, the "magic of a good face-to-face tutorial" and other behavioural phenomena that are commonly found in "co-present", face-to-face communication (such as nonverbal cues and continuous turn-taking) test the skills of tutors (Bork & Rucks-Ahidiana, 2013; Lowe et al., 2016; Trenholm, 2013; Trenholm et al., 2016). In addition to this is the array of technological constraints and affordances that teachers must incorporate into their practice, some of which are doubly demanding for mathematics teachers struggling to overcome the dominance in digital classrooms of "qwerty- and mouse-based communication" and "rigid syntax constraints" (Trenholm et al., 2019).

A strong refrain in studies that examine issues affecting online mathematics education is that "mathematics is different" (Smith et al., 2008; Trenholm, 2013; Trenholm et al., 2019). Here, it is claimed that the various digital platforms that are used for communicating (in written, oral and non-verbal forms) and sharing work with students can flatten the learning environment and make it more difficult for teachers to ply their skill (Meehan & Howard, 2020). It is perhaps not surprising, given the high levels of abstraction and perceived "hardness" of mathematics that students claim they "cannot teach [the subject] to themselves" and expect their learning to be sustained by fulsome instructional guidance (this contrasts with the situation for some humanities subjects, for example, which are perceived as "soft") (Jaggars, 2014; Trenholm, 2013). Standard mathematical instructional techniques, such as instructor modelling of problem solving, animated use of visual-spatial components in diagrams and demonstrations and timely application of corrective feedback, have to be reimagined for online use. This challenges teachers to develop new modes of practice (Smith et al., 2008). A possible consequence of these discipline- specific issues is students' stated preference for studying mathematics, above other disciplines, face to face (Jaggars, 2014; Xu & Jaggars, 2014).

A systemic review of research on online teaching and learning from 2009 to 2018 found that one of the least studied themes was institutional support (Martin et al., 2020). This contrasts with the amount of research attention devoted to the problem of student retention in an online context (Boles et al., 2010; Sorensen & Donovan, 2017; Trenholm et al., 2019) and issues surrounding transition more broadly (Briggs et al., 2012; Hernandez-Martinez et al., 2011). Institutional support of mathematics learning can take many forms but is generally seen as the sum of a set of enabling services whose purpose is to improve students' academic performance, bolster their confidence, instil within them a sense of solidarity and community and dispose them positively towards a discipline that is often perceived to be impenetrably difficult or the source of significant anxiety (Heyman, 2010; Ludwig-Hardman & Dunlap, 2003). More research is required to investigate questions of tutors' and students' perceptions and preferences related to their provision or use of online MSS as this genre is only in its early stages of development. Research that is qualitative and sensitive to the challenges and opportunities presented by COVID-19 is even less prevalent but no less important.

4.3 Background

Western Sydney University (WSU) is a multi-campus university in the western part of Sydney, Australia. In 2019, the university had approximately 50,000 students of which 79% were undergraduate students. WSU is a genuine multi-campus university in the sense that there is no main campus, and many services and degree programmes are available on some or all of the campuses. WSU does not currently list secondary school mathematics as a prerequisite for any degrees.

WSU has had mathematics support staff for over 25 years, although with very few staff in the early years. For example, in 2000, there were the equivalent of 1.5 full-time MSS staff. In 2011, the Mathematics Education Support Hub (MESH) was created to provide MSS to students and MESH currently has the equivalent of just over five full-time staff.

MESH provides support for all students, except for research degree students who need assistance with statistical analyses. Support is usually provided face to face on six campuses as well as an online answer service (a discussion board where staff respond to posts). There is no physical space run by MESH; drop-in MSS is offered at advertised times in various campus libraries and teaching spaces are booked for other MSS activities.

The face-to-face services provided by MESH pre-COVID-19 included drop-in support, test and examination preparation workshops for many first-year subjects[4], workshops run during the 4 weeks before new students begin their formal studies and workshops for particular disciplines (e.g., nursing).

On 18 March 2020, which was Week 3 of a 15-week semester, all face-to-face MESH MSS moved online using Zoom. The drop-in support which had run on six campuses continued to be drop-in support, mostly using audio with students' videos off (by students' choice). Workshops also ran via Zoom, using breakout rooms with mixed use of video, audio and chat. Support remained online for the rest of the year. During the break between Autumn and Spring MESH ran some discipline specific online workshops. In summary, and for the purposes of this study, MESH provided wholly online tutoring/learning for all students for 28 weeks, which for the students in this study was just three weeks short of their full academic year.

University College Dublin (UCD), Ireland, is a research-intensive university currently ranked within the top 1% of higher education institutions world-wide. In 2019/20, UCD had over 32,000 registered students of which 67% were undergraduates and 29% international students. It is consistently the university of first choice among school leavers in Ireland.

The UCD Mathematics Support Centre (MSC) was established in 2004. It is staffed by a full-time manager and approximately 20 tutors are hired each year. These are predominantly graduate students with a handful of undergraduates hired as peer mentors also. Annually, the MSC supports in excess of 5,500 student visits from over 250 distinct subjects across all six colleges of the university. Since October 2015, only students registered to preparatory, first- or second-year subjects may access

[4] In this paper, "subject" refers to what is sometimes called "unit" in Australia and "module" in Ireland where both terms refer to a standard unit of an instructional section within a university program that is a "self-contained" component of instruction.

the MSC. Up to March 2020, apart from a short pilot using Slack.com during peak demand of final examinations, the MSC did not offer synchronous online MSS.

The MSC started providing wholly online MSS from 23 March 2020, Week 8 of the 12-week teaching semester, (January to May) of 2019/20. This was conducted through the institution's virtual learning environment using virtual classroom video conferencing software. All sessions were appointment based with students booking 30 minute slots. Typical sessions were conducted with both tutors' and students' cameras off thus relying on audio and/or chat. The MSC was fully online for first semester 2020/21 (September to December) when MSS ran from Weeks 3 to 12. In contrast to MESH which had 28 weeks of wholly online MSS the MSC provided MSS wholly online for a total of 14 weeks during the COVID-19 period of this study.

The initial move to online MSS saw a dramatic drop in the number of users at both MSC and MESH. From March to May 2020, the end of the second semester, the MSC service experienced a 79% drop in usage on the same period in the previous year. This amounted to 245 visits from 85 distinct students compared to the corresponding figures of 1,149 visits from 412 distinct students in 2019. This was despite the online MSS service remaining open for three extra weeks—the examination period was extended due to COVID-19—which had not been done in previous years.

The MESH drop-in service saw 604 students from April to December 2020, whereas from April to December 2019 there were 1,156 students (a drop of 46%). MESH workshops, almost all of which are held after March, attracted 2,545 students in 2019 and 1,971 in 2020, a drop of 23% (a student is counted each time they use a MESH service).

4.4 Methodology

Data were collected in the form of transcripts emanating from 23 one-on-one Zoom interviews conducted by the lead author from late October to late November 2020. Interviews were conducted with seven WSU students (AS1–AS7), four WSU MESH tutors (AT1–AT4), six UCD students (IS1–IS6) and six UCD MSC tutors (IT1–IT6). The semi-structured interviews ranged in length from 14 to 44 minutes with a mean length of 28 minutes. The interviewer used a single set of questions for both UCD and WSU appropriately adapted for the student/tutor context—the interview questions are available in Appendix E. The interview questions were designed based on the authors' extensive experience as mathematics educators and MSS researchers and previous research highlighted in Section 2 and came about through multiple discussions about MSS in both universities pre- and during the pandemic. The questions were piloted to ensure that they were open enough to allow for rich responses but restricted enough to target the research question.

A comprehensive description of the coding process used for the current study is provided, with the aim that it will act as a template for MSS practitioners and researchers interested in adopting this, or a similar, approach.

4.4.1 Qualitative analysis and coding process

Thematic, deductive, semantic coding, as defined by Braun & Clarke (2006), was used to analyse the interview transcripts. Segments of text that shared a theme in common were labelled (coding), the codes were created based only on the data, not with any theory or expected themes in mind (deductive), and finally, the codes/themes were based on the explicit meaning of the interview text (semantic).

The coding framework was built over four rounds of coding as outlined below and shown in Figure 4.1. Throughout these rounds the primary coder the lead researcher was assisted by the co-researchers in coding to ensure the following: (a) the coding framework was as expansive and well defined as possible; (b) the coding framework was used consistently throughout all 23 interviews; (c) the context of the WSU tutors' and students' interviews was not misunderstood by the UCD-based first author. Through this multi-round, multi-coder process a strong coding framework with consistently coded interviews was created to aid the theme development and identification process that constituted the final step in the analysis. The qualitative analysis software program MAXQDA was used for coding in Rounds 3 and 4, with Microsoft Word and Excel used for Rounds 1 and 2.

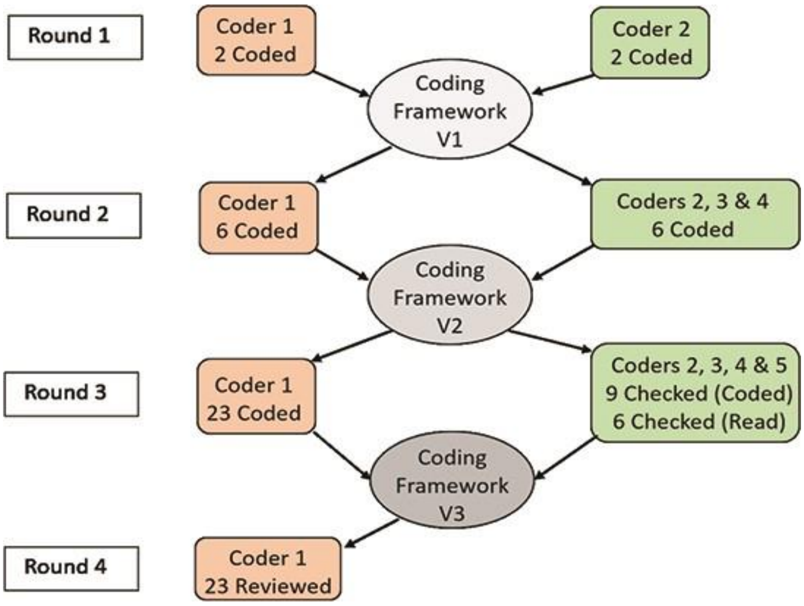

Figure 4.1: Creation of the coding framework over four rounds of coding with five coders.

4.4.1.1 Round 1: Initial coding framework development (n=2 interviews coded)

To build the initial coding framework, the two Irish researchers both independently coded two interviews, a WSU student and a UCD tutor, in accordance with the method outlined by Thomas (2006). This coding was in vitro, meaning segments of the interviews were highlighted and given concise descriptive titles (for example, Issues: Wi-fi). The researchers then exchanged their initial coding frameworks, and the list of codes and their definitions that each researcher used independently in analysing the interviews. They then independently compared their coding frameworks and subsequently met to discuss this and merge the two initial frameworks into one. The two frameworks overlapped significantly and version one of the coding framework, V1, was created.

4.4.1.2 Round 2: Framework clarification and expansion (n=6 interviews coded)

To clarify and expand the coding framework, six further interviews were coded using version one with the intention to add more codes where necessary and develop the definitions of the existing codes. This ensured that the codes were understandable and usable and that as many additional codes as necessary were added to the framework before coding the majority of interviews. The lead researcher coded all six of these interviews, and three others from the research team each coded two or three interviews. Again, this process was conducted independently. Two WSU tutors, two UCD students, one WSU student and one UCD tutor were coded in this round so that version two of the framework would be built upon two interviews from each of the four interviewee groups.

The lead researcher received the coded transcripts from the rest of the team and after comparing each coded interview with their own coded transcripts, organised all codes used in Rounds 1 and 2 with their definitions. The codes created in Round 2 were compared to the codes in version one and were merged with another code where appropriate or added to the framework to create version two, V2, of the coding framework.

4.4.1.3 Round 3: Coding the data set with consistency checks (n=23 interviews coded)

Version two of the coding framework was used for the first round of coding on the other 15 interviews that were not coded in Rounds 1 or 2 and to re-code the eight interviews already coded in Rounds 1 and 2 with version two of the codes. This was completed by the lead researcher; however, checks for consistency using Thomas's (2006) "Check on the clarity of categories" were completed by the other researchers. The lead researcher sent the transcript from an interview they had coded to a fellow researcher, without the codes attached, and the fellow researcher coded the text to ensure reliable use of the coding framework. This process allowed an inter-rater reliability measure to be calculated as outlined by O'Connor and Joffe (2020). If two researchers fell below 80% of consistency of coding then a meeting occurred where the inconsistencies were discussed and resolved. Nine interviews (none of which were coded in Rounds 1 or 2) were checked in this way, with at least 25% of each interviewee group checked. The remaining interviews that were not used in Rounds 1 or 2 were reviewed by one of the other researchers, that is, the lead researcher sent them the coded transcripts. This process ensured that the results of the coding of any interview were not solely dependent on the lead researcher's understanding of the data. Round 3 coding resulted in one new code being added to the framework ("Benefits: Technology") and the consistency checks resulted in more precise definitions for many of the Round 2 codes. This process produced version three, V3, the final version of the coding framework.

4.4.1.4 Round 4: Reviewing codes (n=23 interviews checked)

The coding of all interviews was revised using the final coding framework by the lead researcher and the theme identification was based on this coding.

4.4.1.5 Theme identification

Upon completion of the coding process, identification of the themes highlighted by the coding took place. A key objective of this process was to detect evidence that pointed to any differences in the experience of tutors and students in this new online MSS context while attempting to ascertain the potential impact of these experiences on MSS use in the future, as per the research question. Similarly, attention was paid to any testimony of shared experiences both from a tutor-student perspective and an Australia-Ireland perspective.

4.4.2 Participants

Participants in this study were recruited via email by two of the research team, one inviting WSU students and tutors and the other UCD students and tutors in October 2020. Students from both WSU and UCD were only sent the recruitment email if they had used MESH or MSC services after the transition to online MSS. Those emailed were 890 MESH users and 397 MSC users (231 of which were first-year students who had access to the online MSC only from when they started university in September 2020). All tutors, except the researchers, in both MESH and the MSC (n=11 and n=15, respectively) were emailed and invited to participate as all of them had tutored online during the relevant period of this study.

As stated, seven WSU students (AS1–AS7), four WSU tutors (AT1–AT4), six UCD students (IS1-IS6) and six UCD tutors (IT1–IT6) agreed to be interviewed. The fact that these are convenience samples has imposed limitations on their analysis. However, the student samples were diverse in makeup, based on course, stage, gender, and their pathway to university.

The UCD students were a blend of first and second-year students from both service and specialist mathematics modules. One of these students had used the physical in-centre support service prior to COVID-19 and three were first-year students whose only experience of university was in an online setting. All but one of the UCD tutors were postgraduate students with between three and seven semesters of experience in MSS tutoring, the exception being an experienced MSS tutor who had also lectured in the School of Mathematics and Statistics for several years. The WSU students were five first-year and two second-year students, all studying mathematics as part of a non-mathematics degree. Only one first-year and one second-year student had experienced on-campus MSS. Three of the four WSU tutors had postgraduate qualifications and at least five years' experience in MSS; the fourth tutor had at least two years' experience with MSS tutoring. Contrary to the UCD postgraduate tutors, WSU staff would be classified as "dedicated staff" according to the MSS staffing definition of Lawson et al. (2020, p. 1238).

4.5 Results

Analysis uncovered five themes as central to the shared experiences of tutors and students in the online MSS context of the COVID-19 period of March to November 2020. These are *Usage of online MSS, Mathematics is different, Social interaction, Pedagogical changes* and the *Future of online MSS*. The themes and their subthemes are shown in Figure 4.2. This paper focuses on the first, second and fifth themes as they relate to the research question. As participants' views were largely similar regardless of their institution, the common perspective is presented unless otherwise stated.

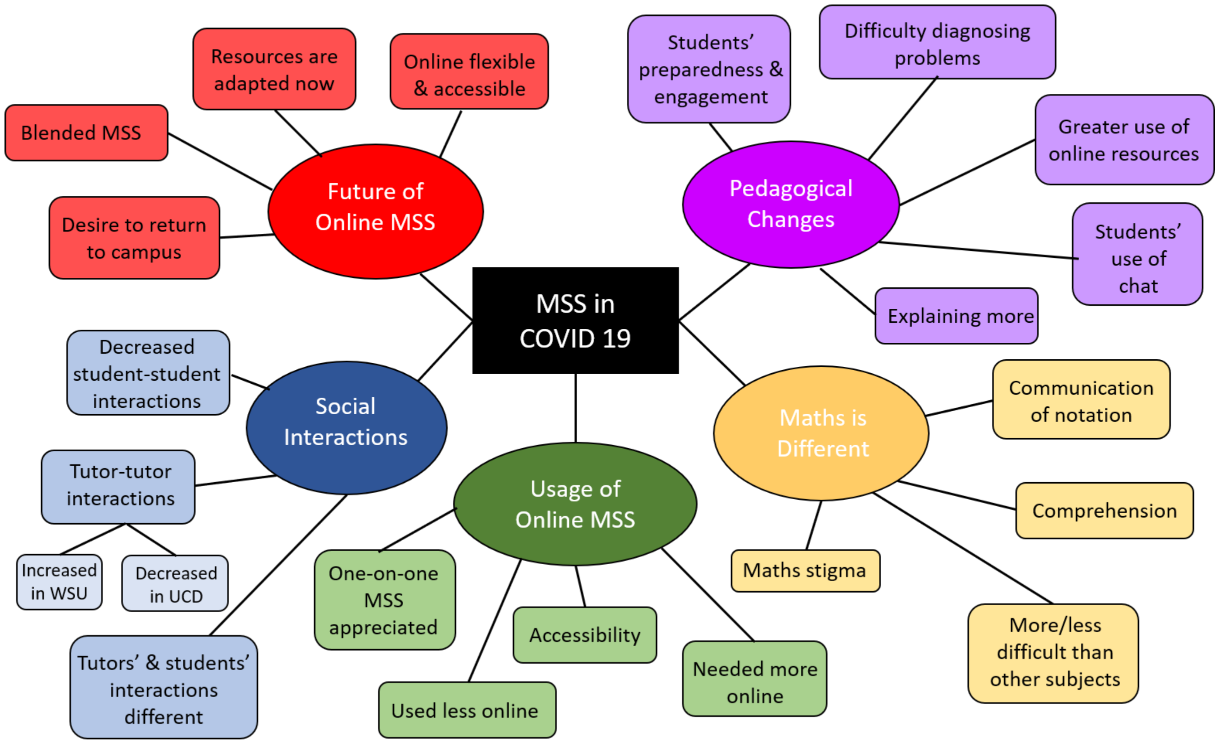

Figure 4.2: The five themes and their subthemes identified in the analysis of the interviews.

4.5.1 Usage of online MSS

As discussed, online MSS was utilised significantly less by students in WSU and UCD during 2020 in comparison with in-person MSS offered previously. The theme of how and why online MSS was used by the students arose in the interviews yielding four subthemes (shown in green rectangular nodes in Figure 4.2), three of which will now be discussed. Tutors and students commented on this decrease in use, and some expanded on why this may have occurred. However, the tutors and students interviewed confirmed there was a core group of students who really appreciated the support offered online, and some were in fact more likely to use online MSS than in-person support.

4.5.1.1 Used less online

Tutors commented on how they saw fewer students online, particularly at the beginning of the wholly online period. One tutor noted online support was "a bit quieter" than the on-campus support despite MESH combining six campuses into one Zoom room facility. They explained:

> I would work at a specific campus, and I might get three or four students in a session but now even though it was all of the campuses put together, like in one session I might not even get that much. … Maybe the students were a bit apprehensive about whether they could actually get help online. (AT4)

UCD tutors spoke similarly about fewer students accessing support online, although one was hopeful that with the increased number of students traditionally using MSS in the autumn (September-December), visits would pick up.

> In the beginning students were very cautious about the whole thing, in that they didn't know how it worked. ... they would be … less likely to just drop in randomly as they would in the in-person MSC, which I think is probably quite a big disadvantage … it's just they would be less likely to when they don't know what they are going into or when they can't take a look from the outside before they are actually in the room. … But I think this semester things are getting a lot busier and students are used to the online thing … I think the longer it will go on online I think the more they will get used to it and the less sort of hesitant they will be. (IT2)

Although online bookings picked up from the start of the next academic year, MSC visits remained relatively low for semester one of 2020/21 with 1,515 online visits compared to 3,127 in-centre visits in the corresponding 2019 period. While tutors were not asked explicitly for reasons why they thought there was a such a drop in MSS usage, IT4 worried that a certain type of student was no longer using MSS: "we still might not be reaching out to the students that would sort of just drop in, like they might have in the library because it was there."

The students helped provide insight into why online MSS might be less accessed than in-person support. AS1 explained that they turn off their computer when studying and while they would have spoken to MESH tutors frequently in the library while studying there, studying at home meant they would have to turn on the computer to speak to MESH tutors. Even when students do turn on their computer they admit it is easier to use YouTube as it is available 24 hours a day. Another student stated that online one-on-one interactions make them anxious, although they had encouraged their fellow students to use MESH:

> Just knowing the support is there is the first thing … when I hear people saying that they're having trouble with it [mathematics] I will try push them towards MESH or PASS or whatever is available. But I'd guess a lot of people … either have trouble working out that they need help or have trouble telling other people that they need help. (AS4)

A UCD student explained a similar situation among their peers, where despite the extra support set up by the MSC, students still cannot attend due to being overwhelmed or fatigued:

> students can be ... not lazy, but like when you're trying to get to all your classes, sometimes it can be hard to go and ... get the energy to reach out to the MSC or reach out to the lecturer and be like, "Oh, I don't get this". The lecturers and tutors are making a massive effort to get us to use the supports, but I don't know if they're being fully used by students. (IS5)

4.5.1.2 Needed more online

In contrast to the decreased use of MSS subtheme, several students believed they used MSS more often when online. AS5, who struggled to connect with their peers online, noted that they probably would have used MESH less if they had study partners to collaborate with:

> if I had study partners I potentially would have used MESH less. But without that I needed that additional support to be able to just have that explanation of why I couldn't figure out the stuff. ... But having that human interaction made a big difference.

UCD students IS2 and IS4 found learning mathematics online brought them to the realisation that getting support can be a positive action. IS4 said:

> it kind of made me realise that sometimes you do need to ask for help but it's not that you are stupid and you don't get it, it's just maybe that there is a gap in the knowledge that needs to be filled.

Both students also stated that they would have used MSS less in person as they were struggling more with mathematics online and so took action by accessing the MSC. IS2 explained that they take great pride in figuring out mathematics independently but found this was not manageable when studying from home due to their increased workload. IS4 found that online mathematics learning made them notice knowledge gaps that would have been filled subconsciously in-person, in part through peer interaction.

Another UCD student, IS5, noted that they were equally likely to use either the in-person or online MSS: "It's probably one of the areas that hasn't changed that much because they adapted really quickly on to online". However, they also commented that "some of my friends are more willing to just do it [access MSS] online as opposed to face-to-face because … you just type it in, it's kind of less, I dunno, as opposed to walking in, I suppose."

4.5.1.3 Accessibility

Online MSS has the potential to be more accessible for some students. AS3 noted: "I think that the accessibility makes you feel more like, look I can actually do this. It's actually more of a possibility. You don't have that excuse of 'I have to go into campus'." AT2 also commented that there was a possibility that the online MESH support might suit students who would not ordinarily have attended in person, whether this was due to timetabling reasons or the safety of greater anonymity. They believed online MSS could attract different personality types. A UCD tutor also thought online support would make it a bit easier for students:

> to come to the support centre and be prepared just because it's kind of easier to there, there's more flexibility on their part in the times they can do. Before it was … you have a free hour in between lectures and … it's kind of the best time to go. And, you can't go in the evening, because maybe you know you have to catch your bus (IT5)

However, they still believed that there were similar or even lower levels of student engagement at the MSC than when in person.

4.5.2 Maths is different

The move to online MSS reinforced the idea that learning and tutoring mathematics and statistics is genuinely different to other subjects. While the interview questions anticipated this, the volume of responses to this notion was surprising. These differences included difficulties in communication between students and tutors, comprehending mathematics online, and the extra concentration required to both tutor mathematics from tutors' perspectives and to absorb content from the students'. Specific disciplines mentioned in comparison to learning and teaching mathematics included commerce, languages, laboratory-based disciplines, medicine, economics, and the so-called "hard" discipline of engineering. Strong comparisons were also made between teaching and learning mathematics in person and online. In terms of conceptual understanding, the need for maximum attentiveness when being tutored was put forward as an extra hurdle when learning mathematics online as opposed to the in-person support setting.

4.5.2.1 More/less difficult than other subjects

The feeling among WSU and UCD tutors was that the move to the online environment has reaffirmed their belief that mathematics is different to other subjects and is generally more challenging to tutor and learn. AT3 expressed their desire to discontinue tutoring mathematics online. They discussed how communicating mathematics specifically is slow and frustrating and that those who have not tried to teach mathematics online do not understand how difficult it is. This was based on their experience of delivering MSS exclusively through Zoom where students used the chat facility and therefore had limited capacity to render mathematical symbols. If their job were to be permanently online, they would leave it[5].

> I think if we had to go online forever I definitely would not want to do that and I'd be looking at ... doing something else. I think it's reinforced that mathematics and statistics are different to most other content areas. It's made me realise how important communication is. (AT3)

Not all tutors were of the opinion that mathematics learning and teaching was more difficult online, with one tutor (AT4) stating that mathematics teaching was no different whether in person or online once the initial adaptation period had been overcome. Despite this opinion, the tutor's response aligned with other tutors interviewed, in that the nature of mathematics impacted their ability to tutor effectively online.

Initially, there was agreement among WSU students about whether mathematics is easier or more difficult to learn online than other subjects. When asked directly, six of the seven WSU students said there was nothing specific about mathematics or statistics that made it more or less difficult to learn online. AS2, who studies science, would happily study their mathematics subjects online, with

[5] An (interviewed) Irish tutor ceased working in MSS from January 2021 due to the move to online tutoring stating they had lost too much connection with both their students and fellow tutors.

their science classes on campus, as mathematics was comparatively more amenable to online learning. AS4 noted that while there was initial difficulty in accessing online academic support, eventually online communities (e.g., using Discord) grew and became active and, as a result, mathematics became easier to learn online. AS6 appreciated seeing mathematical problem solutions "zoomed up in front of your face" as they found it easier to focus on what they were being shown.

However, within the broader scope of their full interview, all of these students reported at least one aspect of mathematics that made it more difficult to learn online. AS1, upon comparing their current mathematics studies with their previous commerce degree, expanded on the difficulties of comprehending mathematical concepts online. They noted that full concentration is needed throughout a mathematical explanation and that missing one step, perhaps as the Wi-Fi loses connection briefly, can cause extra work. All six UCD students identified that there were difficulties in learning mathematics online due to an increased need for understanding in comparison to other subjects. IS5, studying both Economics and Mathematics, compared these subjects:

> My economics studying hasn't changed at all really, because they kind of just put up the material, you go through it, you listen to their slides and then you just give the questions a go and you're grand. Whereas with maths and stats stuff, it's a lot more like, it's all about your own understanding. And I feel like it's become a lot harder to understand something because ... they still explain things, but it's not how they used to ... They're not as ... solid as they used to be.

4.5.2.2 Comprehension

Overall, students stated comprehending mathematics on their own without support takes longer online and that complete explanations and concepts are easier to understand in-person. Two Irish students spoke about the need to understand the concepts in mathematics which, for them, was a difficult process. It is not useful to just "learn it off" by heart (IS4) instead, students have to understand "where they [concepts] come from, how they are meant to work, and why they work" (IS2).

Even when students accessed online MSS, due to the difficulty in communicating mathematics online there was still a barrier to complete understanding as highlighted by IS4:

> In maths it's concepts and sometimes trying to maybe explain the concept you are confused by is difficult enough, let alone if you are trying to do it through a screen. They're trying to help but ... you don't fully know what you are confused by, so they don't really know how to help you to be less confused.

These difficulties in learning mathematics online caused two students (IS3 and AS7) to consider deferring future mathematics courses until they were available as in-person courses. IS3 explained throughout their interview that they enjoyed "hands-on maths" and they found it too difficult to learn mathematics online as this practical feature was significantly decreased. AS7 stated that in-person mathematics teaching was far more engaging and they would also prefer not to be assessed online any longer.

4.5.2.3 Communication of notation

The physical act of writing and drawing mathematics, both for tutors and students, was hindered in the online MSS environment. As time progressed, it was evident that tutors, in particular, became more equipped with the requisite technologies (tablet, stylus, etc.) to mitigate these issues, but not every student had such luxuries.

In terms of specific content, tutors expressed more difficulty in supporting applied mathematics, when “there’s just so much writing to get through” (IT1), and computer programming or coding online (in particular R and Python) than in-person. However, IT6 and AT1 who also gave regular coding tutorials found tutoring coding to a class online easier than in person, though the situation was reversed when it came to coding in the one-on-one MSS context. In this setting, the tutor and student needed to see (a) the question, (b) the student’s attempt and (c) the tutor’s intervention which ideally required the same code to be run and displayed on one screen, which is easier to do in-person when the tutor may work on the student’s machine.

At a more granular level, tutors struggled with communicating mathematical notation, language, and symbols; and annotating student work. In particular, the use of language specific to mathematics was a barrier to communication, with one tutor saying: “Things like, they’d be reading out their equation to you and, it’s really difficult to read out mathematics, no one should ever do it.” (IT1), and another stating: “We’ve students trying to type maths into the chat, because that’s the only way they’ve got to communicate and it really makes it much harder than other subjects” (AT3). A third tutor noted that in addition to students’ difficulty in being unable to write numerical scripts, tutors also felt the loss of being able to check the setting out of students’ work. This was difficult to achieve when annotating virtual whiteboards that got “messy”. They summed up their feelings about communicating mathematics online stating “You can talk about it but there is nothing like doing it and seeing it. So I think that was missing a little bit. I found that quite difficult” (AT2). This sentiment was clearly echoed among all tutors interviewed.

4.5.2.4 Maths stigma

Another distinguishing feature of mathematics is the widespread acceptance that it is okay to dislike or be unable to learn mathematics. Motivating such students, as reported by tutors, is much harder online than in person where physical gestures and verbal encouragement, based on students’ body language and work, can be more empowering:

> without the kind of real physical ... facial expressions, say “I believe in you”. Without that it’s definitely a little bit more difficult, I would imagine than other subjects, just because the general feeling is “No, I don’t like maths”. (IT3)

One student also referenced stereotypes around mathematics that require addressing whether in person or online:

> I'm not sure if it's more difficult to learn online, but there's ... the whole mental health thing. There is this weird stigma about maths ... I think there needs to be a shift there, but it hasn't been less difficult, I don't think. (IS1)

In summary, tutors and students identified many aspects of mathematics learning that are affected by the move online, some positive but mostly negative.

4.5.3 Future of online MSS

With less MSS engagement, and difficulties of online learning exacerbated by the nature of mathematics, students and tutors interviewed aspired for the future of MSS to be different to its current pandemic-enforced online state. However, some positives to online MSS have revealed themselves through the forced move and so participants do not wish the future to look exactly like previous on-campus MSS.

4.5.3.1 Blended MSS

While the majority of tutors can speak to various benefits of online MSS such as greater accessibility afforded by video conferencing compared to travelling to campus (particularly in WSU's multi-campus structure), none of the tutors interviewed would like MSS to continue in a fully online setting. Most tutors were open to a blended form going forward:

> To be honest, I started off being a little afraid of coming online. I think it's just, because I'm not used to it, but I found it to be much better than I thought it would be. Maybe not in programming or computers, but in other ways it's definitely an option. Like if someone were to suggest 50 50 in person or online, there's certainly a lot of queries that students have that are 100% like you can do them in 10 minutes online kind of thing. (IT1)

The hybrid model seems to be a viable option among WSU tutors with AT1 and AT4 speaking extensively on this. As AT1 explains, it must be designed with students' needs in mind:

> I think it's good to have that online option always there. I don't think it's a good idea to go ... even with something like MESH, to go completely online because, like I said, some students just don't have the technology to learn and be comfortable with it; but at the same time, for all the students who are comfortable I think it's definitely good to have that online option there; especially at Western Sydney because we have so many different campuses.

4.5.3.2 Resources are adapted now

Tutors who have found a way to make online MSS work were hesitant to give it all up again once students and staff were back on campus. Even AT3, who would not continue working as a tutor if MESH was permanently online, would not like to see the online resources they spent many hours creating never used again, "I wouldn't say that I prefer them, but I think they're valuable."

4.5.3.3 Online flexible and accessible

Students vary more widely in their opinion of what type of MSS they would like to receive in the future. Some first-year students interviewed had not experienced on-campus MSS and so were unable to compare. While some expressed dislike for their entire mathematics learning being online, WSU students as a whole were keen to keep online drop-in MSS for its convenience and flexibility. AS1 said: “I would like to keep up with the online interactions, because the days I don’t go on campus, ... it will be excellent.”

4.5.3.4 Desire to return to campus

The WSU students did, however, express a desire for some return to on-campus support as that longed for in-person interaction is just not possible by Zoom:

> I think the face to face you get more of that, ... like somebody will want to explain a little bit more to you because they can see your face and see your interaction, if you don’t get it. Although you can do that in Zoom, but because of the time limitation in Zoom, sometimes it’s just not easy. (AS1)

UCD students were even stronger in their preference for in-centre support, with those who had not experienced it eager to find out what it was like. IS3 stated: “And the in-person centre, I haven’t gone there yet. Once I get the chance, I’ll definitely be like in-person working.” UCD students who had experienced in-centre support were eager to return to campus and leave behind all the technical problems experienced with online MSS:

> I suppose most of the time it’s grand, they are there to help you and explain what you are confused by. But sometimes if you have connectivity issues or they are trying to share their screen but their screen gets frozen ... this happens more times than you think; you are trying to have the question up and then have the screen up and then also maybe share your notes you have written yourself, as well, and then … it’s a lot easier to sit down beside someone. You have your page; you look at the page, and you write on the page. (IS4)

One student, IS1, spoke to the psychology of in-person versus online support and believed being in-person helped in confronting problems—a key element of MSS for them. “I believe that if you confront your problems with people around you, it’s a really good boost to your confidence and individual development. I think that’s important; that people don’t hide behind the screen so much.”

There is no mistaking tutors’ desire to return to work on campus—to interact fully with students, to be able to use body language, and to see all of the work clearly in one place, instead of swapping between computer screens. As IT2 explained:

> I think I prefer being able to see someone; as in face to face; and just real time reactions and that sort of thing. I prefer working with a pen and paper just because it’s faster first of all, and because you can bring emphasis to parts of it a lot easier. (IT2)

While the majority of tutors were now comfortable with working online and were ready and willing to continue with online work in some fashion, on-campus support was preferable. As AT3 noted, when online they did not get “that buzz” from tutoring, as they did in-person.

In general, there was acceptance that online MSS can be effective in certain situations where the student is comfortable working in that environment. However, the strong desire to be in-person, and hence back on campus, was evident among the study’s participants.

4.6 Discussion

This study has brought to light a range of issues related to the provision of online MSS in the COVID-19 era. The themes outlined in the results section, concerning MSS usage patterns, the distinguished nature of mathematics as a difficult discipline to learn and support online, and attitudes to how support provisions might be re-imagined in a post-COVID world, stand apart but are linked. Emergent questions about the relationship between students' use of mathematics learning support and their perceptions of the value of online learning in this discipline could be explored further in research with a narrower focus than the present scoping study. Similarly, the perceptions of students, who have only experienced online study, of the challenges and opportunities of studying mathematics online could be compared to the perceptions of students who have received some in-person instruction.

While many of the issues raised in this paper have been accounted for in a large corpus of online higher educational literature, it must be emphasised that this study highlights the experiences of students and tutors of mathematics engaging with their study and practice during the COVID-19 pandemic. It is interesting that many of the themes in related studies that predate the pandemic resonate with those that have emerged in this study. This fact should pose questions for practitioners and researchers of MSS, and also senior management, about the implications of mathematics being different (Smith et al., 2008; Trenholm, 2013; Trenholm et al., 2019), what can be done about reduced usage in online support provision and in what ways support services should be remodelled for post-pandemic delivery.

The theme addressing students' and tutors' use of online MSS raises a number of questions. The fact that usage has dramatically decreased at WSU and UCD (as reported in Section 4.3, and as seen in Hodds, 2020 and Johns & Mills, 2021) suggests challenges for support providers related to accessibility, use and availability of technology, staffing, and advertising. Reasons for the decrease cited by the interviewees span problems in adjusting to online learning platforms and media, the perceived anxiety-inducing nature of online support when it comes to the intensity of one-on-one interaction in a confined digital environment and fatigue or depleted motivation due to the "overwhelming" experience of studying online during the pandemic. Some students studying off-campus found it easier to search the web for resources than to join an online session or make an appointment, whereas on campus it was easier to use drop-in support. An interesting contrast in the student responses was that while support usage dropped, those who used the online services available to them valued it at least as much as the in-person offerings available to them at earlier times. This could be due to an increased need among students for support in study routines affected by isolation (from peers and tutors) and less opportunity for incidental "corridor" discussion. Two UCD students stated that they used MSS more online than in person; however, it was the lack of interaction with others that was behind the desire for extra assistance and this overrode the disadvantages of online MSS outlined in Section 4.5.2.

The theme highlighting aspects of online mathematics teaching, learning and support that mark it as different from other disciplines emerged from the interview responses as a compelling testament to something the authors, as experienced mathematics educators and researchers, have long been aware of in their own practice: the technologies and environments used for online mathematics learning can enable but also impede such things as effective written, oral and non-verbal communication, corrective feedback mechanisms, modelling of methods and solutions, use of visual-spatial explanations and instructional efficiency. The expanded discussions of the discipline-specific characteristics of mathematics given in Trenholm et al. (2019), Protopsaltis & Baumi (2019), Trenholm (2013), Paechter & Maier (2010) and Smith et al. (2008) reinforce these ideas and highlight the need for research in this space that is centred in the discipline.

With respect to online communication of mathematical concepts and methods, there was a consensus view among the interviewees that this was complicated by the idiosyncratic nature of the discipline. The problem of how to induct students into use of technology to write mathematical symbols and organize text according to strict layout conventions was raised, alongside the perceived awkwardness of out-loud readings of mathematical phenomena (such as equations). In addition to the limitations encountered in notating, mathematical language was the problem of easily conveying meaning in the language itself, primarily due to the fact that crude platforms (such as Zoom chat) were being used clumsily in situations that, were the exchanges to happen in person, might be dealt with by a swift verbal or written interaction. These issues, whose effect has been to hinder teaching and learning, are well documented and serve as a reminder that to date no universally accepted and effective online substitute has been found for in-person communication of mathematics (Meehan & Howard, 2020; Trenholm et al., 2019).

These challenges had follow-on effects in disabling many tutors' basic pedagogical functions such as checking the set out of students' work and stepping them through explanations in a more assured manner than was possible in transient, digitally mediated spaces. In many cases, tutors had to adjust their practice to compensate for faces that were not seen and voices that were not heard (Trenholm, 2013). A problem of space arose here, with tutors reporting the difficulty of juggling multiple interfaces (virtual whiteboards, browsers, software applications, lesson worksheets, etc.) at the same time in order simply to establish a display for demonstration and discussion with students. A possible implication of this is that mathematics tutors, due to feelings of frustration, incapacity or restraint, develop negative attitudes to working in online environments and contemplate quitting or suffer a style of disillusionment that impacts the quality of their tutoring. There is substantial evidence in this study that tutors and students recognize the benefits of operating online, so the task for practitioners and management is to be honest about the above-mentioned disabling factors in plotting a way forward that solidifies these benefits but minimizes the challenges. “Best practice” guides for online MSS will no doubt be useful in this endeavour (Johns & Mills, 2021).

Perhaps the most consequential finding to emerge within the “mathematics is different” theme was that, due to its conceptual and sequential nature, mathematics demanded special attention from, and placed special cognitive stresses upon, students and tutors. According to the student interviewees, this put it at odds with other disciplines and rendered it more difficult to learn in situations absent of human co-presence, a sense of community (among peers, for example) and the opportunity for ‘short-cycle’ instruction (Trenholm et al., 2016). In fact, as far as some students (and two tutors) were concerned, this was sufficient reason for them to avoid studying (or tutoring) mathematics subjects online, if such a choice were open to them. This study makes no claim about any objective measures of difference between the conceptual demands of mathematics compared to other disciplines, but it is noteworthy that this issue appeared so prominently in the response data—perhaps indicating a widely held perception or stigma that has tangible effects on the engagement behaviours of students and tutors.

Considering the fact that, with the move online, the MSS tutors interviewed lost physical presenting space, the ability to see students’ work and communicate in subtle ways using body language, it was not surprising to learn of their strong desire to return to campus. Most students, struggling with the more independent nature of online learning, as well as pandemic-enforced isolation, expressed a similar desire. This affirms reporting in the pre-pandemic literature of students’ preferences for in-person mathematics study (Jaggars, 2014; Xu & Jaggars, 2014). Unfortunately, at the time of writing, such a return is not possible at UCD and in only limited ways at WSU. The opinions of students and tutors reported here can inform future MSS plans. Students’ perception that they cannot teach themselves mathematics (Jaggars, 2014; Trenholm, 2013) is a problem that needs further, and urgent, research as many universities recalibrate their learning support programs in response to the pressures of COVID-19. Exploration of the struggles of tutors in adjusting their in-person pedagogy for online use is also needed, perhaps framed by the contestable notion of the pre-eminence of pedagogy over medium (Jaggars, 2014; Trenholm, 2013). The benefits of online MSS that have been identified here—tutors and students appreciating its flexibility, students liking its affordance of anonymity and tutors valuing its provision of new learning resources—must be considered when deciding how to deliver online MSS in the post-pandemic world. Wider evidence of these benefits should also be factored in, but with an awareness of the presence in the literature of over-hyped commentary (Danielson et al., 2014; Figlio, 2016; Jaggars, 2014; Protopsaltis & Baumi, 2019; Trenholm, 2013; Trenholm et al., 2016). With regard to students’ attitudes towards post-pandemic use of online MSS, there were some situations identified as amenable to support in this setting. Once students become comfortable with the online environment, it is possible that MSS usage will increase overall if both on-campus and online options are made available and are seen as attractive. In any blended offering, however, it is clear that students and tutors would prefer in-person support to have precedence.

In the short term, those responsible for planning and delivering MSS must acknowledge the issues affecting online support raised in this study and, where possible, try to find solutions. Why students are using MSS less in the online versus in-person mode is still unclear and is a fertile topic for further investigation. Despite possibly new cohorts of students being attracted to MSS because of its online options, the overall decline in users indicates that there are many students going without much needed support (a fact which could impact measures of success and retention). The students and tutors featured in this study have adapted reasonably well to the challenges of communicating online but the fact that it is a slower and more difficult process has planning implications: how much time and how many resources should be given to online MSS?

4.7 Conclusion

The benefits and challenges of delivering and receiving online MSS in the COVID-19 era under the themes of *Usage of online MSS*, *Mathematics is different*, and *Future of online MSS* highlighted in this study indicate how much MSS provision has changed and will continue to evolve. More research into why students are not using online as much as on-campus MSS, and ways to improve online communication, is needed to help MSS practitioners and researchers to understand, adapt to and perhaps capitalize upon this change. Moreover, this study did not focus on the experiences of students unwilling or unable to engage in synchronous MSS sessions, a key piece of the puzzle in gaining a fuller picture of online MSS engagement.

While each MSS provision has its own requirements and demands, there is definitely commonality when it comes to meeting the needs of students and ensuring student satisfaction with the service. These needs have been exacerbated by the COVID-19 pandemic due, in part, to the special nature of mathematics and the difficulty of tutoring and learning mathematics online. The significant decrease in student usage of MSS has implications for the future of online MSS. There is a strong desire to return to in-centre support, but with online services continuing in some capacity, showing how the pandemic-enforced move to online learning has permanently changed MSS.

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5 The rapid move to online mathematics support: changes in pedagogy and social interaction

Abstract

The dramatic changes brought on by the COVID-19 pandemic have changed the way in which mathematics and statistics support is offered. Students and staff have been presented with new opportunities and challenges. One-on-one interviews were conducted late in 2020 with 23 students and staff who had experience with fully online mathematics and statistics support. The interviewees were from University College Dublin, Ireland, and Western Sydney University, Australia. Utilising thematic analysis, five themes around online mathematics and statistics support common to both universities were identified. In this paper the three themes related to *connection* are explored; they are pedagogical changes, social interaction, and appreciation of mathematics and statistics support. These themes highlight the need felt by both students and staff for mutual connection. The paper concludes with a discussion on the repercussions of this study for future considerations of effective online mathematics and statistics support.

5.1 Introduction

The enforced closure in March 2020 of many university campuses due to the COVID- 19 pandemic resulted in major changes and developments in how students and educators interact. In particular, academic support systems such as mathematics and statis- tics support (MSS), have had to adapt in real time to changes in teaching, learning, assessment and engagement, among other factors, in order to best preserve the student support that existed, and was so successful, for those who engaged with it before the pandemic hit.

This paper outlines the context of MSS both online and in-person, before and during the pandemic. The experiences of students and tutors in the wholly online environment focussing on central themes of changed pedagogy and social interaction will be examined.

5.2 Literature review

5.2.1 Mathematics and statistics support

Mathematics and statistics support in universities is free, optional assistance for students with mathematics and statistics which is not part of scheduled classes and is not taken for credit (Lawson et al., 2020; MacGillivray, 2009; O'Sullivan et al., 2014).

MSS was in the past seen to be primarily for engineering and the physical sciences, however these days MSS is provided for, and used by, students from many disciplines and at many different levels, including postgraduate students (Lawson et al., 2020; MacGillivray, 2009). Such support has become business as usual in most universities in Australia (MacGillivray, 2009), Ireland (Cronin et al., 2016), the UK (Grove et al., 2020) and the USA (Mills et al., 2020). Lawson and Croft (2021) note that the rise of dedicated student support centres has been slower in continental Europe and Liebendörfer et al. (2017) reported in 2017 that, while most German universities offer bridging courses, there are not many support centres.

In Australia and Ireland, formal MSS has existed for many years (Cronin et al., 2016; MacGillivray, 2009). This support was established in response to what is commonly called "the mathematics problem" and its variants (Lawson et al., 2020). In Australia, decreasing levels of mathematics studied at secondary school (Barrington & Brown, 2014; Forgasz, 2006) coupled with an increase in the number of students taking on university study (Productivity Commission, 2019) led to an increased need for universities to provide mathematics learning support. The lack of prerequisites for many courses in many universities (e.g., Belward et al., 2011) exacerbates the problem as some universities admit students to degrees with a strong quantitative component without considering their mathematical knowledge or whether or not they have studied mathematics beyond age 16.

In Ireland there has also been concern about the declining mathematical performance of secondary school students and the lack of preparation of students for tertiary study (Gill et al., 2010; Hourigan & O'Donoghue, 2007). Recent mathematics curriculum reform and a bonus points[6] initiative for those choosing the higher level mathematics course at upper secondary school have seen the number of students taking higher mathematics increase steadily – from 15.8% in 2011 to 32.9% in 2019. However, concerns now exist around students who may not be suited for higher mathematics but persevere for the bonus points, as this increase in uptake has not been matched by an increase in mathematical proficiency (O'Meara et al., 2020).

In both countries the primary provision of MSS has been the drop-in model, in which students access assistance from an expert tutor of their own volition. Often students seek one-on-one help with their mathematical/statistical queries, though it is not unusual for small groups of students to access such support. Many studies have evaluated the effectiveness of MSS and most have found a link between the use of MSS and benefits to students in a plethora of ways, for example, improved retention, grades, confidence and employment prospects (Matthews et al., 2013).

There are many ways in which MSS is delivered. There is considerable evidence in recent literature that drop-in and one-on-one bookable MSS are the most common modes of support. A 2018 survey of MSS in England and Wales found that in 96% of institutions MSS included drop-in support or one-on-one support by appointment, with 55% offering both modes of support (Grove et al., 2020). In Ireland in 2015, 88% of institutions offered drop-in MSS and 44% offered support by appointment (Cronin et al., 2016). In Scotland in 2017 the most common forms of support were drop-in and on-on-one support (Ahmed et al., 2018). Lawson et al. (2020) note the importance of the tutors in these forms of one- on-one support, with Johns and Mills (2021) pointing out that one-on-one tutoring allows tutors to work with each student in their Zone of Proximal Development (Vygotsky, 1978). There is a wide variety of other forms of MSS including bridging courses, supplementary instruction and workshops, pre-assessment problem-solving workshops, small group sessions, student worksheets, commercial online tutoring programmes, online revision modules, online question and answer services and the use of internet resources (Bressoud et al., 2015; Grove et al., 2020; Jackson, 2020; Johns & Mills, 2021; Lawson et al., 2020; Rylands & Shearman, 2018). Some support is embedded within teaching (Grove et al., 2020) and indeed informs teaching (Cronin, 2019; Cronin et al., 2019; Cronin & Meehan, 2020).

Online MSS has not been as common as face-to-face support, however it is not new (Cronin & Breen, 2015). Johns and Mills (2021) report that one-on-one online MSS has existed since the early 2000s, although the majority of MSS is on campus. Online support can be synchronous via video or

[6] Introduced in 2012, the Bonus Points initiative meant mathematics was afforded unique status as a subject for school leavers with an extra 25 points (from a maximum of 100) being awarded for a passing grade (at least 40%).

using text; or asynchronous, perhaps using a discussion board. In Australia, before COVID-19, Jackson and Johnson (2013) used online tutoring software together with face-to-face support, Rylands and Shearman (2015) reported on the use of both online software and face-to-face workshops and Dzator and Dzator (2020) offered drop-in and bookable MSS face-to-face as well as online support. In the survey of England and Wales already mentioned (Grove et al., 2020), 23% of institutions offered online live MSS, the majority for less than one hour a week.

In March 2020, the COVID-19 pandemic resulted in the closure of university campuses around the world, and thus the closure of face-to-face MSS. Almost all universities in the UK and the USA reported on by Hodds (2020) and Johns and Mills (2021), respectively, moved to offering support online. Two problems mentioned with online MSS were issues with internet connections, and difficulties communicating mathematical notation with not all students and staff having appropriate equipment (e.g., a tablet). Both studies, as well as Mullen et al. (2021), found that in most cases the use of MSS decreased after the move from face-to-face support to online support.

Face-to-face interactions between students and tutors, which typically included being in the same room and working together at a table or board, were replaced, sometimes overnight, with wholly online MSS, often with limited institutional technological support. New ways of online communication, teaching and formative assessment were used by staff who largely had no experience or training in online MSS, changing how they and students interact and how learning and teaching occurred.

5.2.2 Online Pedagogy

In transferring their practice from face-to-face to online environments, teachers had to rethink how they interact with their students and the extent to which familiar "campus- based" pedagogical strategies can be effectively employed in virtual learning spaces. Mathematics teachers, in particular, strived to map their established "ways of doing" onto the multifarious digital platforms that support online learning (examples given in Trenholm & Peschke, 2020 include student-led learning, use of discussion and collaboration, "free and extemporaneous" communication of symbolic notation and diagrams, non-verbal messaging, and well-timed question-response-feedback cycles). A concern is that this process does not always respect the transformational nature of the transition, and that the re- contextualized use of essentially unaltered traditional pedagogies might not be the best response (Carrillo & Flores, 2020).

The discipline dimension of this problem goes further. In Trenholm (2013), Trenholm notes the effect of the epistemology of different disciplines on pedagogical development (citing the work of Lattuca & Stark, 1995, where cumulative, linear and tightly structured knowledge growth in the natural sciences is distinguished from the recursive, reiterative and loosely-structured patterns of development in the humanities; and where pedagogical approaches focus on concepts and principles (natural sciences) as opposed to effective thinking (humanities)). This has implications for mathematics educators struggling to adopt the “de-disciplined”, uniform approaches to online teaching and assessment imposed on them from higher faculty or institutional levels (Trenholm, 2013). Moreover, it overlooks discipline-specific challenges in mathematical education such as the hierarchical nature of concept development, the predominance of abstraction and the need for strict adherence to principles of logic and proof.

From a practical point of view, teachers have less access in online teaching spaces to the sometimes subtle cues from students indicating discomfit, confusion, waning engagement or, on the positive side, moments of insight or “ah-ha” comprehension (Bork & Rucks-Ahidiana, 2013; Lowe et al., 2016). In Smith et al. (2008) mathematics is cast as a “foreign language”, making it ill-suited to instruction in online environments which offer fewer opportunities for corrective feedback and “multi-modal immersion” than face-to-face set- tings. The idea that the conceptual landscape of mathematics is different from that of “soft-knowledge” disciplines (Lattuca & Stark, 1995), and that it is more difficult for students to navigate it online compared to face-to-face, has inspired discussion of students’ discipline-specific preferences for in-person learning (Otter et al., 2013). But as online education evolves, and protocols and manuals for expert use of learning technologies such as web conferencing (see Levy, 2020 for example) continue to improve, it is possible that some of these concerns will fade.

Profiles of students who are best suited to online learning – particularly those under- taking mathematical study – typically refer to concepts such as self-sufficient, self-directed, self-disciplined, self-motivated, self-organized and independent among others (Gaytan, 2015; Heyman, 2010; Ituma, 2011; Jaggars, 2014; Ludwig-Hardman & Dunlap, 2003; O’Neill et al., 2004; Otter et al., 2013; Protopsaltis & Baumi, 2019; Xu & Jaggars, 2013). Common to all of these is the notion that in order to succeed in online environments, students must be able to regulate their own learning (Broadbent & Poon, 2015; Martin et al., 2020). But not all students possess self-regulatory learning capabilities upon entry to university, and so it is likely that, in the absence of appropriate pedagogies, those who do are privileged (Reinhold et al., 2021).

As mentioned above, attempts to transfer face-to-face pedagogies to online settings often assume that all that is needed is a mere re-deployment of skills and principles rather than the development of new, transformed approaches that privilege the digital media through which they are actualized (Coupland et al., 2016; Trenholm et al., 2016). This presents a challenge and, perhaps, an opportunity: how can the best of the “old” methods and philosophies be re-purposed for use in the “new” context in such a way that students’ mathematical development is optimized and continues to be the central educational focus? A related challenge is one of standards and measurement (and their effects on teaching): how can “depth of understanding” in mathematics be measured in a standardised way across all modalities so that it is sensitive to achievements not directly amenable to commonly-used assessments? (Coupland et al., 2016)

5.2.3 Social interaction

The theme of social interaction has featured prominently in discussions of online education since the early to mid-1990s. At this time many of the theories developed to define and understand distance education were updated to accommodate the emerging "computer-mediated" (and networked) educational world (Garrison, 1993; Jonassen et al., 1995). Studies considered the role of social relationships and group cohesion in enabling meaningful collaboration online, particularly dialogue in activating the "cognitive processes necessary for deep learning and information retention" (Kreijns et al., 2003, p. 335, and see Johnson & Johnson, 1987 for a broader discussion of socially-mediated learning). Today, the ubiquity of online learning has led researchers to examine what has been lost and gained in the transition from face-to-face to digital modalities, especially as it relates to "live" interaction and communication (Meehan & Howard, 2020; Trenholm, 2013). An interesting perspective offered by Trenholm and Peschke (2020) is that – per McLuhan's aphorism "the medium is the message" (McLuhan, 1964) – the internet has fundamentally transformed the "what" and "how" of teaching and learning, meaning that efforts to simply re-direct or re-assemble traditional face-to-face approaches are doomed to fail (Trenholm & Peschke, 2020).

Teachers' and students' expectations have grown with the development of online learning technologies: if opportunities for dynamic, immediate, human-to-human communication are considered essential to high quality online learning, student success and retention, then what is being done to make these available? (Bower et al., 2015; Heyman, 2010; Protopsaltis & Baumi, 2019). This is true also of informal social interaction, where students see value in study-related conversations with their peers and teachers outside of timetabled classes (Meehan & Howard, 2020), and where the loss of opportunity for "human exchange" is considered a distinct disadvantage (Cassibba et al., 2021). The provision of an online learning community is seen as important for students in creating a "feeling of connectedness", a sense of belonging and a resource for knowledge construction and growth (Händel et al., 2020, p. 2). From the teachers' point of view, little research has been done on the "lived experience" of practitioners interacting with each other (online or face-to-face) in collegial communities (Grove & Croft, 2019), a situation this paper aims to address.

Instructional design and teaching practice are informed by frameworks validating the central role of social interaction in online education (see Arbaugh et al., 2008; Benson & Samarawickrema, 2009 for examples). In their survey of interaction and presence in online learning environments, Kyei-Blankson et al. cite two theories of distance education that "have been advanced in the discussion of effectiveness of online courses" (Kyei-Blankson et al., 2019, pp. 48–50). Interaction is a primary element in both of these: Transactional Distance (Moore, 1993), where interaction and perceived pedagogical distance are assumed to be inversely related; and Community of Inquiry (Garrison et al., 2000), where “social presence” is deemed critical. A third theory, Communities of Practice (Wenger, 1998), frames learning in terms of four interconnected social components – “community (learning as belonging), identity (learning as becoming), meaning (learning as experience), and practice (learning as doing)” (Trenholm & Peschke, 2020, p. 3).

The construct of social presence is referred to frequently in the literature but is poorly defined (Lowenthal & Snelson, 2017). While many definitions assume the existence of a “real person” who is (in some sense) “there” in online communications, there is little consensus on precisely what this means (examples include non-machine, emotionally available, present and actively engaged) (Lowenthal & Snelson, 2017). Notwithstanding these definitional issues, there is evidence of a positive relationship between social presence (of teachers and peers) and student satisfaction with their online learning (Carrillo & Flores, 2020; Richardson et al., 2017). Related correlations highlight the value of social presence – manifested as meaningful feedback or fully engaged instruction, for example – in enabling students to feel less isolated and disconnected in their online study, but question the extent to which disembodied digital learning environments can provide the same level of “socio-emotional information” as face-to-face settings (Paechter & Maier, 2010; Sorensen & Donovan, 2017).

There is much to be studied in this new environment. This paper explores the following research question:

What were the effects of the rapid change to fully online MSS on pedagogy and interactions among tutors and students?

5.3 Background

Western Sydney University (WSU) came into existence in 1989. It is a multi-campus university with more than half a dozen campuses in the west of Sydney, Australia. Many degrees can be studied on several campuses and students can, and do, study on more than one campus. In 2019 the university had approximately 50,000 students of whom 79% were undergraduates.

Mathematics and statistics support has been provided by the Mathematics Education Support Hub (MESH) for the last decade. MESH currently has the equivalent of just over five full-time staff and casual staff are also employed during the semester. MESH tutors would be classified as “dedicated staff” according to the MSS staffing definition of Lawson et al. (2020, p. 1238). The university has offered MSS for over 25 years, though with fewer staff than at present.

There are no secondary school mathematics prerequisites for entry to WSU, so many students are mathematically poorly prepared for their studies. MSS is provided to all students regardless of discipline or subject[7] studied. Before the COVID-19 pandemic, MESH provided face-to-face support on six campuses. This support included refresher courses for students about to begin their studies at WSU, drop-in support in campus libraries and workshops run for specific subjects and student cohorts. For many years MESH has run an online answer service via a discussion board. Over the last decade MESH has built up comprehensive support materials which are available to all students via the learning management system and MESH web pages.

All MESH services ran fully online from the 18th of March 2020, the third week of a 15 week semester. One year later MESH has only just returned to running a few workshops on campus. From the point of view of the study reported in this paper, all MESH services were online for 28 weeks, which for the students in this study was just three weeks short of their full academic year.

University College Dublin (UCD), Ireland, founded in 1854, is one of Europe's leading research-intensive universities and Ireland's largest university with over 33,000 registered students. It is consistently the university-of-first-choice among school leavers in Ireland.

The UCD Mathematics Support Centre (MSC) was established in 2004. Due to demand, since 2015 only students from preparatory, first- or second-year subjects may access the MSC. In these past five years the MSC received 29,707 student visits from over 400 subjects across all six colleges of the university – Arts and Humanities, Business, Engineering and Architecture, Health and Agricultural Sciences, Social Sciences and Law, and Science. The majority of these visits emanate from the library drop-in one-on-one service. In addition 'Hot Topic' sessions for groups of students, similar to the workshops at MESH, are offered. The MSC is staffed by two to five tutors at any given time with approximately 20 tutors hired each year. Tutors are predominantly postgraduate research students with no formal pedagogical training. Most MSC tutors also tutor regular tutorials and many go on to teach within tertiary or secondary education professionally. Also, final stage undergraduates serve as (near-)peer tutors for first-year MSC visitors. Up to March 2020, apart from a short pilot using Slack.com during busy examination periods, the MSC had not offered any personalized synchronous online MSS.

The MSC started providing wholly online MSS from the 23rd of March, 2020 – Week 8 of the 12-week teaching Spring semester (January to May) of the 2019/20 academic year. The MSC was fully online for the Autumn semester of 2020/21 (September to December) when it ran from Weeks 3–12. In contrast then to MESH which had 28 weeks of wholly online MSS (three weeks short of a full academic year) the MSC provided MSS wholly online for a total of 14 weeks during the COVID-19 period of this study.

[7] In this paper "subject" refers to what is sometimes called "unit" in Australia and "module" in Ireland where both terms refer to a standard unit of an instructional section within a university programme, that is a "self-contained" component of instruction.

The pandemic has had a significant impact on MSS engagement at both institutions. At UCD the MSC drop-in figures decreased by 59% on the previous year's visits (4283 to 1762 visits) for the corresponding period (April–December 2020), while WSU drop-in service figures decreased by 46% and the MESH workshops had a drop of 23% for the same period (Mullen et al., 2021).

5.4 Method

The data comprises of transcripts emanating from 23 one-on-one Zoom interviews conducted by the lead author in late 2020. A single set of questions was used for UCD and WSU, appropriately adapted for the student/tutor context – see Appendix E. The questions were tested with non-participants of this study to ensure that they encouraged responses relevant to the research, without being too narrow.

Participants were recruited via email by the second author (WSU students and tutors) and the third author (UCD students and tutors) in October 2020. Students from WSU and UCD were sent the recruitment email if they had used MESH or MSC services after the transition to online MSS. Those emailed were n = 890 MESH users and n = 397 MSC users (231 of which were first-year students who only had access to the online MSC from when they started university in September 2020). Tutors, excluding the authors of this paper, from both MESH and the MSC (n = 11 and n = 15 respectively) were emailed and invited to participate as they had all tutored online for the entire period March to October 2020 of this study.

Table 5.1: The participants.

Participants	Background information	MSS experience
UCD students IS1-IS6	Mix of specialist and service mathematics; 2 first years, 3 second years	1 student had used on campus and online MSS, 5 had used only online MSS
WSU students AS1-AS7	All service mathematics; 5 first years, 2 second years	2 students had used on campus and online MSS, 5 had used only online MSS
UCD tutors IT1-IT6	Part-time tutors; 5 postgraduate tutors, 1 lecturer/tutor	Postgraduates had 3-7 semesters MSS experience, lecturer/tutor had several years of MSS experience
WSU tutors AT1-AT4	Dedicated tutors; 3 had postgraduate qualifications	3 had at least 5 years' MSS experience, 1 had over 2 years' MSS experience

Seven WSU students (AS1–AS7), four WSU tutors (AT1–AT4), six UCD students (IS1- IS6), and six UCD tutors (IT1–IT6) participated. There were convenience sample limitations but the student samples were diverse in terms of degree major, gender and age, that is recent school leavers or mature status. Background information about the participants is provided in Table 5.1.

Thematic, deductive, semantic coding (Braun & Clarke, 2006) was used to analyse interview transcripts. The coding framework was developed over four rounds as outlined in Mullen et al. (2021) and shown in Figure 5.1: Round 1 was to establish a basic coding framework which was developed in Rounds 2 and 3, concluding with a final review for consistency in Round 4. Throughout these rounds the primary coder, and lead author, was assisted by the co-authors to ensure: (a) the coding framework was expansive and well-defined; (b) the coding framework was consistent throughout all 23 interviews; and (c) the context of WSU tutors' and students' interviews was not misunderstood by the UCD-based interviewer. Through this multi-round, multi-coder process a robust coding framework was created to aid the theme development and identification process that constituted the final step of analysis. In each round coding was completed independently by the authors using methods outlined in Thomas (2006). Coding was then compared through discussion using an inter-rater reliability measure of at least 80% as outlined in O'Connor and Joffe (2020).

Coding concluded with the identification of themes highlighted by this process. Key to this process was the detection of evidence highlighting any differences in the experience of tutors and students in the context of online MSS, while also attending to potential impacts of these experiences on MSS in post-COVID-19 settings. Similarly, attention was paid to any testimony of shared experiences both from tutor-student and Australia-Ireland perspectives.

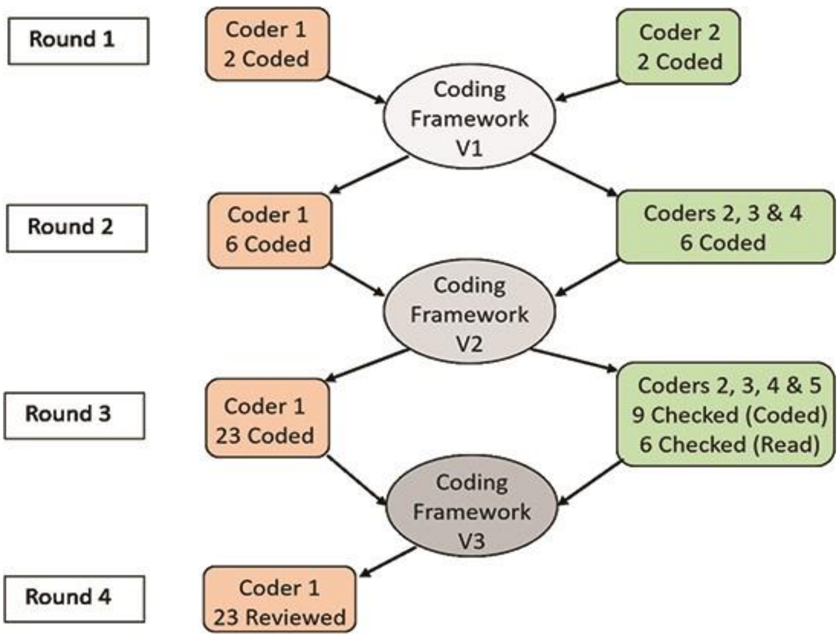

Figure 5.1: Creation of the coding framework over four rounds of coding with five coders.

5.5 Results

Five themes were identified as central to the shared experiences and perspectives of tutors and students in the online MSS context of the COVID-19 period of March to November 2020. These are *Usage of online MSS*, *Mathematics is different*, *Pedagogical changes*, *Social interaction*, and the *Future of online MSS*. The themes and their subthemes are shown in Figure 5.2. Based on the research question, the third and fourth themes together with part of the first theme are now examined. A detailed discussion of the themes not covered in this paper can be found in Mullen et al. (2021).

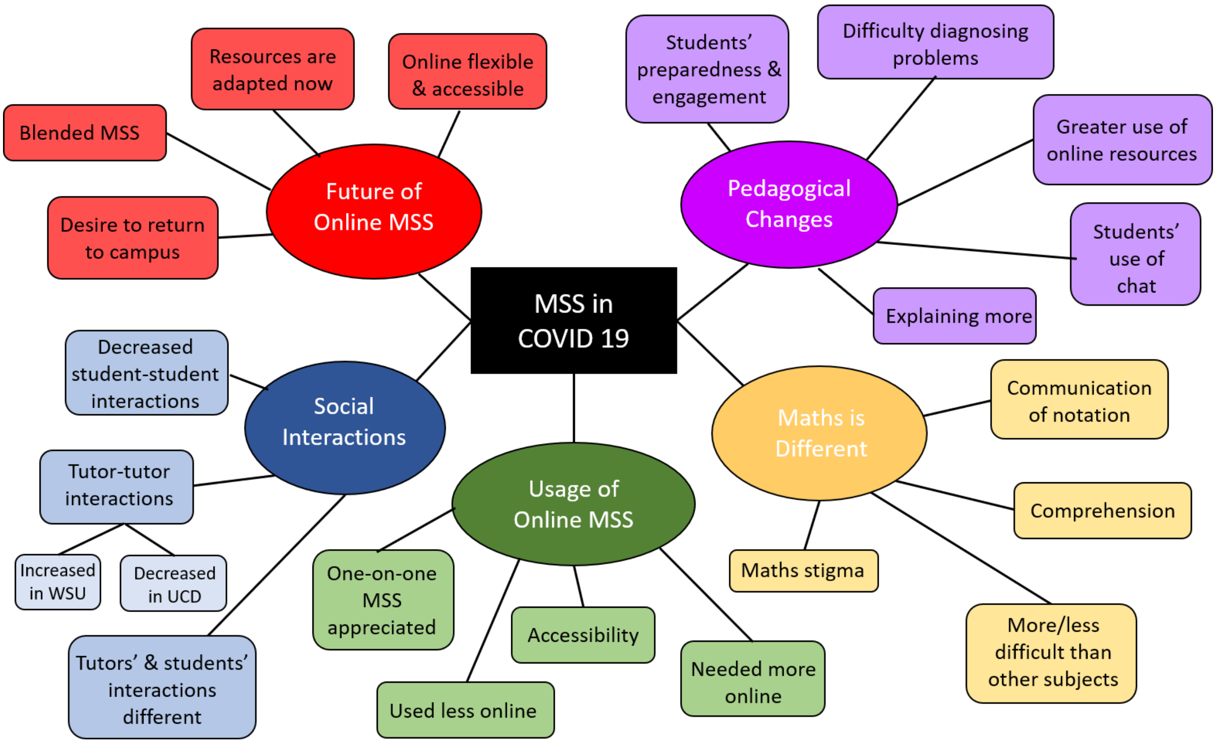

Figure 5.2: The five themes and their subthemes identified in the analysis of the interviews.

5.5.1 Pedagogical changes

The pedagogical changes observed by tutors to have arisen from the rapid shift to online MSS yielded five subthemes (shown in the purple rectangular nodes in Figure 5.2). The tutors noted a reduced capacity to communicate with students online – especially via body language or other non-verbal exchanges – and see their work, either at all or as it was being written. This made diagnosing students' problems harder and complicated tutors' use of familiar in-person teaching strategies such as thinking time, guided questioning and treatment of misconceptions. These changes caused a shift among tutors to a more didactic teaching approach, one where they talked to students a lot more and answered their questions more completely than they would in in-person settings. The tutors found that having easier access to relevant learning resources online improved their confidence as well-informed teachers but that this came at a cost: students needed greater guidance in filtering out the best resources from the vast, uncurated, array of learning materials served up to them on the internet. Tutors also observed an increased willingness of students to communicate in online lectures and tutorials via chat, but this was not as visible in the MSS context. On the question of students' preparedness and engagement when studying online, UCD and WSU tutors' highlighted different experiences. UCD tutors found that students were often more prepared for online MSS sessions but some were taking less notes in online lectures. WSU tutors pointed out the difficulties of engaging students in group work. These pedagogical challenges and benefits associated with online mathematics tutoring will now be explored in further depth.

5.5.1.1 Difficulty diagnosing problems

One of the greatest challenges tutors identified regarding online teaching was the loss or lack of body language or non-verbal communication. Students in UCD and WSU tended to turn their cameras off (if they had a camera) during online support interactions and tutors found this limited their ability to interpret students' level of understanding. IT2 explained how a student's facial expression clearly portrays how much they understand an explanation:

> You can tell very easily face-to-face when they're having issues, even when you are describing something to them and they're lost, it shows in their face very quickly, whereas if they're just saying "yes" in their voice you can sometimes catch it; but probably not always.

AT3 discussed the loss of connection with their students online and how not being able to see the student or their mathematical work is difficult:

> I just feel like I'm not really connecting with the student. If they suddenly get something and understand it, I'm not receiving the message that they have understood it. And if they have not understood, it's much harder to identify what it is that they're not understanding when I can't see their working.

This issue of not being able to identify student's precise misunderstandings without seeing students' work was echoed by IT1 who also noted that they felt less comfortable online with the "thinking time" they give students.

> [I]n face-to-face teaching, if you ask them a question it's a lot easier to leave that silence and let them think it out. Whereas online, if I ask them a question and they don't respond, I assume technology errors . . . It's a lot easier to write things out with the students face-to-face and see their thinking. Whereas when online, unless they're writing it out and showing it to me, which means you probably have to take something else off the screen, I can't see where they've gone wrong.

Tutors and students had trouble communicating mathematics with each other without pen and paper. Due to technological difficulties, among others, tutors were less able to see students' work and this led to awkward situations.

> some students are more technology savvy than others. Some students really struggle with sharing, sharing notes, sharing different things, and students can get away with stuff more. Like if you say, "have you made a previous attempt at this question?" They can just say, "yes, but I'm not able to show it to you" and you have to say, "Oh, okay". (IT1)

IT6 had difficulty understanding students' questions, due to technological difficulties:

> Sometimes students aren't able to turn on their mics . . . or don't have one. So they're trying to type out their questions and when they're very technical, it can be quite difficult to communicate what exactly is meant.

5.5.1.2 Explaining more

These communication issues, especially the loss of non-verbal communication, sometimes resulted in tutors using a more didactic style of teaching online than they would adopt in person. AT2 was concerned they were talking at, rather than to, students:

> I am not quite sure how it's been received, and I hope I am not talking at them. When you are face-to-face you can immediately see if you've used a word they didn't understand. You know what maybe needs to go back and be repeated. I think students don't get those cues unless they are very comfortable putting something in chat. So I didn't personally find it hard to talk to them, I think some of them found we didn't have a normal interaction. I think the back and forth was missing.

Tutors also reported that they tended to coach students more closely and answer their questions more fully when online. While in person they feel comfortable leaving students "hanging" in a workshop because they can return to them; online they find students move on from difficult questions when the tutor is not in the breakout room.

> So there might be a tendency to guide them a bit more closely, to ensure that they have got something out of it. I am talking about if you're looking after four or five breakout groups yourself, getting back regularly enough to see is a bit more difficult. They can easily leave and they can easily change questions while you are gone. The number of times they said "Oh we left that one out" and I would say "That is the idea of being here, that you ask about the ones you can't do". (AT2)

AT4 also noted they "talk a lot more" and IT1 stated they explain more too, though this was because of time limited 30 min appointments at the online MSC rather than monitoring multiple breakout rooms as in MESH workshops.

> Definitely it takes a bit longer now to figure out the root of their problem. And I think, in some ways, I'm more likely to help the student a bit more, whereas before I would have kind of left them alone to work out their problem and kind of come and gone from them. Whereas now when their appointment is done, it's done. (IT1)

The tutors as a whole had a preference for in-person interaction. They found it easier to provide explanations suitable to students' level with both the students' body language and their work in front of them.

5.5.1.3 Greater use of online resources

Tutors did appreciate the increased ease they felt in referencing mathematics resources during an online tutoring session.

> I am a little bit more comfortable online. The main reason being . . . especially with something like MESH, we can get questions about literally anything and when it's online . . . I can easily look up stuff and that really helps. (AT1)

IT3 also felt more confident being able to double check online resources during tutoring sessions:

> Funnily enough I am probably a little bit more confident giving help online, purely because I have the power to go and look something up if I need to . . . when you are doing it face-to-face you can still go and look something up and that's fine, but I think you can do it much quicker [online], you can do it while you teach and you can have a few things going on at the same time. I can back myself up a bit more online.

The online resources that the tutors found helpful were also available to the students, and, as AT2 warns, this can be problematic for them. They noted that helping students to identify the best resources online was now part of being an MSS tutor and this will continue whether online or not.

> whilst they always search things online and did things online, because we are forcing them online they are looking more broadly for solutions and in some cases they then became aware that it's hard to select the right application, the right question, that right method that is being asked for any particular question; because there is so much out there, finding your way through it is difficult. So you're trying to help students monitor or discern the best options.

5.5.1.4 Students' use of chat

Some MSS tutors interviewed, who also lecture or tutor outside of MSS, reported how students were more confident to speak up in lectures and tutorials by using the chat facility than they might be in person. IT2 discussed how the way they provide support has changed since COVID-19, and reflected on how this new student confidence appears in the MSS context:

> Even with the MSC stuff the way that we bring them into a room just separately entirely from everyone else, they don't have anyone else around them. I guess that is a little different, maybe they would be more likely to ask what they would perceive as more silly questions and that sort of thing. Otherwise I don't really think there is that much [change].

IT2's perception that students being more confident asking questions online has not affected MSS too much is reasonable, as IT6 noted, students come to MSS "actively seeking help" and thus are prepared to communicate.

5.5.1.5 Students' preparedness and engagement

All UCD tutors discussed how the students they see online prepare differently for their support sessions than in person.

> I find that they tend to be more prepared when they're coming to the online MSC; just because they're more likely to have a question to show you, as in sharing their screen and showing you, than when they are in person and they don't have their laptop next to them and they're like "I need help with this problem sheet but I don't have it here" sort of thing. (IT2)

Contrary to IT2, IT5 found that not all students are prepared for their sessions online but did state that there are more prepared students online.

> It varies. There's always a number of students who seem out of their depth when they come to you with a problem, like they're not quite sure what they're asking you. They just know they don't know something. And other students who are very articulate about the nature of the problem. And others who like basically have the problem entirely solved . . . and as soon as you say one little thing they instantly get it and they barely need you at all . . . there are always those types of students in both online and offline. But, the number of students who seem more prepared seems larger than it did before.

IT3, on the other hand, was concerned about students not taking notes while learning online leading to them seeing students who are underprepared compared to how they might be in person.

> I've seen a lot of people who are struggling are also not taking notes. Sometimes for some students it could just be a bit much and a bit overwhelming and then they have this thing of "I'm just not going to look at any of it and I will just get help from people when I need it and they will explain everything to me" it can get a little bit difficult then because as a MSC person I am going "I need you to have a little bit in you to be able to help you. I can't just teach you everything from scratch". So in that case it's more difficult, because at least in person when you ask them "Have you got your notes with you?", they might have some scribbles on a page and it's something, it's better than nothing.

While UCD tutors discussed the varying levels of student preparation in the online setting, the focus of the WSU tutors was on the difficulty of getting students to engage in group work during online workshops and the extra resources required.

> The issue online was that it was difficult initially to get students to engage in a group. It took a long time to organize the groups to talk to each other, to learn how to share a whiteboard and we found quite a few students quite hesitant to work as a group. Quite a few of them decided they would work on their own and literally there was no conversation going on. So we needed a lot of staff to monitor that situation. In fact we decided that we probably needed twice as long and at least twice as many staff to run the same workshop as we would have done face-to-face. (AT2)

Assessing students' understanding via group work in MESH workshops was also more difficult online, requiring new pedagogical methods.

> With some of our workshops we now put a few questions up at the start, in the form of a poll, . . . which gives us at least a little bit of feedback as to their understanding of the topic; previously, we've not really bothered doing that because as we walked around the room, we get a fairly good sense where they're at anyway, so that has changed. (AT3)

Naturally the theme of pedagogical changes did not arise frequently within student interviews. Student comments that did refer to pedagogy confirmed they also noticed the negative impact due to the lack of body language, difficulties in showing their work and an overall decrease in the "interactive element of learning" as IS5 noted. The students also spoke about their increased use of online resources (other than MSS and those recommended by instructors) and some noted they feel more confident in speaking up online. The increased difficulty of engaging online due to lower attention span and learning using technology was also discussed by students. Clearly both issues have repercussions for tutors' pedagogy online.

5.5.2 Social interaction

The ways in which tutors and students interacted online yielded three subthemes (shown in the blue rectangular nodes in Figure 5.2). With respect to tutor-tutor interactions, the experiences of UCD and WSU tutors were different: while UCD tutors suffered a drop in collegial interaction online (and the loss of community and camaraderie that followed from this), the WSU tutors enjoyed greater collegial connection. Interactions between tutors and students were marked by a loss of rapport and connection and, in some cases, a more business-like mode of engagement. Some students accessed MSS as a way to replace the lost opportunities for peer-to-peer interaction due to the pandemic. A major concern for students was the lack of peer connection online and the effects of this on the quality of their learning. A significant observation was that much valuable mathematical learning can occur socially among peers and that this happens most effectively in in-person interactions.

5.5.2.1 Tutor-tutor interactions

For MESH tutors, the move online created a need to become familiar with Zoom. Thus, as AT3 discussed, they began meeting daily on Zoom and so their time spent together as a team increased.

> Previously our team would have a face-to-face meeting maybe two/three times a year and a Zoom meeting maybe another three times a year. When COVID happened we started having daily Zoom meetings, partly to socialise, partly to practice the technology.

Pre-COVID-19, MESH operated with one tutor in each of the libraries whereas during COVID-19 there were two tutors in one Zoom room simultaneously. This was quite a change as AT4 reflected:

> When you do it face-to-face, you're really quite radically on your own, to the extent that you don't see your colleagues from month to month. And so, I suppose it's paradoxical that in an online format, you're more in contact with your colleagues than before.

All MESH tutors appreciated this increase in interaction with AT1 highlighting one benefit in team teaching where one tutor could assist with a query another tutor might not be familiar with, stating "the tutors complemented each other".

In contrast to the WSU tutors who found they could support each other more online, the UCD tutors who, pre-COVID, worked with two to five tutors in the same room, found they were more disconnected online. This was attributed to tutors taking students into breakout rooms individually and the fact there were usually only two tutors online per shift.

> Most of the time I'm just working with one other tutor now, whereas before I would've been on with far more. It means that when I'm with just one other tutor I know them a bit better, but overall, when we were in person, we would have had far more time to talk to each other and say, "Oh, are you good with Python? Do you want to swap?" whereas now it's harder to have contact with two people at one time in two separate chat bars and in person. So I talked to them less overall, which is sad. (IT1)

Tutors at UCD were used to and appreciated collaborating but found it difficult to do this online due to the added digital barriers as IT2 discussed:

> If you've a quick question for another tutor it's a lot more difficult, whereas before you would be interrupting but it wouldn't feel as much like an interruption because you're not leaving your room, breaking into their room, and then asking them a question. So I would be more hesitant, if I have a problem, to ask other tutors now. I think there is also less interaction when, it's not as busy in the MSC, because it's a lot easier to just mute your mic and go off and do other work . . . Whereas when you're actually in the MSC you'd just sit around chatting if that ever happened.

The social element of working as a MSC tutor has been negatively impacted with many tutors in agreement with IT2. IT6 was saddened by the loss of community and IT3 noted that while the work is still being done there is less camaraderie between tutors.

> Communication is definitely still there when it needs to be to get work done and problems solved But in terms of general upbeat feeling about work and general happiness surrounded by friends and stuff, definitely there is not as much.

The Irish students also noted reduced interaction online between UCD tutors, in comparison to in-centre.

> They're [tutors] obviously in the same room. Like last year if they couldn't get something they'd call one of the others. Whereas now, I was online and one of them didn't know what to do, and he had to go email another one to ask and we're sitting waiting, and it was very different. (IS5)

5.5.2.2 Tutors' and students' interactions different

Tutors also reported loss of rapport with students. IT6 found themselves "cracking more jokes and just trying to get the morale up" because interacting with students could be "weird". AT4 noted students were:

> more business-like over Zoom. I have a lot of regulars face-to-face, you get to know them and start talking about life. And then you might even continue just talking to people until the next student comes in. But you found that because there were more students [waiting] and because, I suppose in the back of the mind you've got the person who's the host thinking what's that person doing in that breakout room, and so you tend to be more focussed and business-like about your interactions.

IT1 reflected that while interacting with one student online is manageable, two or more students simultaneously was difficult:

> It works well when you see one person. When you see two, it almost loses its effect then, but when you have a group of people online and you're trying to help each of them, because, tutoring is slightly different to lecturing or teaching, you want everyone to be interacting. It gets too messy and it doesn't work as well. Whereas in person that was fine.

Students, however, were not using MSS in groups as much online according to their tutors.

> There are far fewer groups of students. I guess some of them will show up as half a social thing and half as a students' thing. They show up with two/three friends and get help but they're not really doing that any more. The only way you end up working in a group is that if there are several people from the same module there who don't necessarily know each other. They just happen to be there for the same module. (IT2)

IT4 believed that lack of interaction among students was a major problem with online learning, and led to "bewildered and lost" students.

Students spoke extensively about the loss of connection with their peers and tutors/lecturers caused by moving online. AS3, talking about this new disembodied relationship with their instructors, said:

> You don't have that personal connection as such. There is a little bit of human taken away from it. So, it's not as . . . well still friendly, but . . . you haven't got that next level of

communication. You haven't got the body language. I wouldn't go as far as saying I am disconnected, but it's just not as connected.

5.5.2.3 Decreased student-student interaction

Most comments on social interactions were students who spoke about the lack of peer interaction online.

> We don't actually talk much to other students so whether in a lecture or whatever, there's not much interaction . . . unless workshops, we try to do our best, but you can see there's a reservation in people. (AS1)

AS5 discussed how they use MESH more because they found themselves unable to connect with their peers online. AS6 too appreciated MESH, as that was the only opportunity they had to interact with fellow students:

> The main thing is mostly you don't interact with students. Okay, other than the MESH workshops . . . they're the only ones where they let you interact with other students, so it helps you to learn which it does. But generally speaking, in all my university classes there's no interaction whatsoever. And they [instructors] even turn off the chat bar function.

However, student experience of interactive online sessions varied with AS7 finding their peers were less committed to interacting online:

> Contributors don't turn on the camera and they even hesitate to type in chat. When you're in a physical environment that's a more collaborative environment. There's no black screen to hide behind. You've already mentally committed yourself to being there. So if you're in the classroom and you're already there, you're committed to at least learning. When you're in person, you can't ignore a question for 5, 10 minutes, get back to that later. That happens in the online collaborative environment, there's no commitment, or there's less commitment because you have to be committed to at least be there in the first place, but commitment is significantly less.

In contrast, AS4 enjoyed online socialisation:

> I think that when I'm online I can banter a little bit and just make jokes about other things, whereas in person most of my social interaction is telling people how to do the work. People ask questions of me and I'm a fairly smart guy and so I'm like "I'll help you".

AS3 found online MESH workshops to be similar to on-campus workshops apart from an increased concern about interrupting their peers:

> I did have one group session that was face-to-face with MESH and it was fairly similar because you take your problem, you do it, and then if you came to a problem you would say "Hey I've got an issue, have a look at my working" and show it to the person next to you, whereas I think on Zoom you can do a similar thing, but I think you're more concerned about interrupting your peers.

IS4, on the other hand, described working with their peers online as difficult and very different from in person where they could easily discuss mathematical problems and found their peers explained potential points of confusion. However, online they found:

> there is no option for a proper discussion and even through a screen it's still completely different because you're trying to get help and there could be connectivity issues and then they're sharing a screen and trying to write on the screen and then you're kind of writing on the screen too and it's just not good. (IS4)

Other students similarly reported that their peers aid their comprehension of mathematics in person.

> I just feel like it's already harder to comprehend stuff when you're looking at a screen and not being interactive in person. When you are surrounded in class by everyone it's more easy to focus and understand what is being taught and engage. (IS6)

IS5 found that their mathematical learning was more peer-dependent than they realized:

> One of the biggest things is none of us realised how learning maths is quite social in that when we're sitting in the lectures and tutorials, without realizing, we spoke to each other so much and, just even silly questions, came up in the tutorials. Whereas when you're on your own now, . . . it's staring at the screen and you're like, I've no idea what's going on here.

IS5 expanded on this point of the importance of peer support saying:

> a lot of my support before COVID came from my friends, without me knowing, in that we'd be sitting together at lunch and someone would be like, "Oh, do you know how to do that?" And you're just constantly listening to people, talking about stuff. So it went in without you realizing, whereas now it's like, you don't have that as much, . . . if I don't actively go look online for someone to help me with my issues with questions, there's no other way to do it.

AS1 echoed IS5's sentiments on how peer-to-peer teaching used to occur more before COVID-19 noting that it has changed how they use MSS as a result, with a shift to seeking help individually:

> Online we don't really work in groups as often as we used to do in the library where one person would just go in and seek help and then they teach all the other people in the group. And that's how we would learn, by teaching one another. What happens is that actually supports what you learn, that you're able to teach somebody else. And in this instance, we just have to go individually, because, it's hard to work in a group via Zoom.

Students also found that their peers aided their engagement with AS4 stating "being in a group of my peers, like, not one-on-one, makes it a lot easier [to receive support]". IS1, speaking for their fellow students said:

> Others mentioned the loss of the classroom environment went against their concentration. Whereas if you are in a classroom environment you would be a bit more up and alert.

These reports of difficulty engaging due to a lack of peer interaction coupled with student accounts of poorer attention spans and mathematical comprehension difficulties clearly affected students' learning online.

5.5.3 Usage of online MSS

As mentioned in the background section, online MSS was significantly under-utilised in comparison to its in-person format. The smaller number of students who did use online MSS was nonetheless very appreciative of it and praised the features that distinguished it from subject-based tutorials or lectures. For example, they noted the individualized, inter- active and equitable nature of the support they received, and the fact that MSS tutors gave them more time to share and work through their problems.

5.5.3.1 One-on-one MSS appreciated

Clearly the MSS provided by WSU and UCD aided students in what still proves to be a difficult learning environment. Some tutors reflected on this:

> I get a lot more students who are willing to just have a conversation. They are not popping in wanting to get their answers and then leaving. They are more popping in, getting their answers, and then saying “How does this work for modules? How do I do this with certain exams? Who should I talk to about this? What do you think about x, y and z?” I think more so students like the idea that they can actually have a conversation with someone and maybe they feel a little bit daunted about asking a tutor or lecturer as they see them in a position that is way above them. not that the lecturers and tutors aren’t friendly but it gives you a chance to be friendlier in the MSC. It’s a little less formal. So overall they just have the chance to be a little bit more open about things that they are concerned about. And I think getting more one-to-one chat with someone who has probably gone through something similar in terms of their degree, tends to calm them down quite a bit. (IT3)

The students seemed to really appreciate the one-on-one interaction MSS provided. As IS1 commented:

> I really felt in a privileged position there because it’s like your own personal maths assistant and you can flesh out your problem in a completely frank way. I think sometimes in the classroom, somebody might be embarrassed For me, that’s the main difference, because sometimes you want more of the tutor’s time and so the online support has been amazing.

IS2 and IS3, both identifying interactive learning as important, enjoyed how the MSC provided some interaction with IS3 saying the MSC is where they “get the more hands on thing, even if it’s not like in person”. IS5 explained that the MSC is:

> the best way to ask the questions cause you have your mic on, you can describe what the problem is they have the whiteboards, so you can share documents, you can speak to them. It’s more like you’re equals, you’re talking to them, it’s a lot easier to communicate because it’s just asking your question rather than trying to type the numbers and stuff.

UCD students found that there often was not enough time in large online tutorials to have all their questions answered and so they used the MSC. IS4 explained that they try to book in with their subject’s tutor in the MSC and this has “made me feel closer to the tutors because I have actually had more one-on-one time with them than in the tutorials”.

The WSU students were similarly appreciative of MESH with AS3 noting that it:

> reinforced the idea that there are people there to help you, that they don’t expect you to go through university just by yourself and lock yourself away and don’t talk to anyone, if you’ve got a problem just keep working at it until you drive yourself insane. I think that they’re doing it for us to reinforce that idea that, yes, we’re actually here to help you.

AS2 also mentioned how MESH helped them and how enthusiastic the tutors were:

> It really helps to know that I’ve got a support network of just people who are there and are on standby to help me out. Yeah, especially getting the emails to me. I can just write them something and they helped me out; because they’re really keen, when they jump online.

Online learning has brought much student appreciation for the service MSS provides despite the changes to pedagogy and social interaction.

5.5.4 Discussion

The results indicate that the rapid move to online MSS has led to a range of pedagogical changes. These include a decrease of non-verbal communication leading to difficulty diagnosing students' issues; technological difficulties hindering communication; and struggles to determine students' knowledge of the topic(s) under discussion. This has negatively impacted the tutor-student discourse and forced tutors to utilize a didactic, rather than dialectic, style of teaching. The suggestion in Lowe et al. (2016) of a reduction in student and tutor dialogue in online compared to in-person settings is explained in Bork and Rucks-Ahidiana (2013) by the relative absence of "socialisation processes" that allow deeper, "multi-modal" connection between the parties (Smith et al., 2008). The absence of in-person interaction allied with tutors' difficulty in accessing visual cues is just one of the communication issues highlighted in this paper that will require further research in the pursuit of effective online MSS.

One of the major strengths of MSS is that it affords opportunities for tutors to assist students with their queries and encourage independent learning by using students' thinking and getting students to 'hold the pen'. The evidence from this study indicates that, due to the transition to online tutoring, a more tutor-led approach was adopted which may affect students' long-term learning as a less independent mindset is fostered. The perception of tutors' that it is mostly better-prepared students seeking help online could compound this problem. An implication of the tutor-led approach discussed in Lowe et al. (2016) is that, in reducing opportunities for free dialogue, it increases the "structure" of online lessons. A finding of the review in Martin et al. (2020) (and references therein) is not only that learning strategies such as time management, metacognition, goal setting and effort regulation correlate positively with academic success, but that there is also a "positive relationship between a learner's self-regulation and interaction . . . communication and collaboration" (p. 9). A mitigating factor is that many students have the ability to turn on cameras and provide tutors with some pedagogically beneficial non-verbal communication cues. How- ever, this requires careful negotiation by tutors as not all students may be in a position to have cameras on.

MSS tutors benefited from increased ease of access to online resources while tutoring online but were concerned about how students were using such materials. Tutors' pedagogical choices are affected by students' knowledge and they feel there is a need and responsibility to guide students in appropriate resource selection.

It is clear that online MSS requires a different set of pedagogical and technological skills. Common techniques such as giving students thinking time are harder to implement. Thus research into appropriate tools and techniques for online MSS is needed to inform staff development. Training in the management of one-on-one and especially student group interactions could prove to be beneficial for MSS tutors, with a couple of caveats: any institutional support should be discipline-specific and do more than merely reassemble traditional approaches (Trenholm, 2013). As emphasized in Hodds (2020) and Johns and Mills (2021), all participants should have access to technologies required for their online learning and teaching, including a device suitable for writing mathematics (for example, a tablet).

The tutor and student responses comparing the nature and importance of social interaction in online and in-person MSS have revealed some strong themes. The most prominent theme was a perception of the relative disconnectedness of the online teaching and learning experience. Tutors reported struggling to engage with disembodied students, whose online presence was often reduced to stilted Zoom chat, or faceless audio. Students complained about the loss of casual in-person interactions that would happen in classroom settings or incidental social situations outside of class. This is not surprising given the findings of the Australian Student Experience Survey, which received responses from 280,301 students in 2020. Compared to 2019, there was a large drop in learner engagement (16 percentage points), and in working with other students as part of university study (14 percentage points) (The Social Research Centre, 2021). Again this interaction loss is concerning, especially given the role of social interaction in enabling deep learning (Johnson & Johnson, 1987; Kreijns et al., 2003), and a strong sense of community and connection (Händel et al., 2020).

Alongside this generally negative set of attitudes were some rays of light. Students appreciated moments of informal interaction with their peers online, and were grateful for any opportunity to communicate with friends. WSU tutors appreciated the enhanced collegiality that came from more frequent interactions with their fellow tutors in Zoom, and the wider opportunity for co-teaching online – particularly as it was possible to accommodate tutors' subject specializations.

In contrast to WSU tutors, UCD tutors' observations about collegial interaction online highlight what has been lost: incidental conversation that would happen during "down time" in in-person MSS sessions; camaraderie and a sense of community. It must be noted that WSU and UCD staff worked differently before the move to online MSS. Because of the multi-campus nature of WSU, tutors worked in isolation when on campus, whereas multiple UCD tutors worked in the same room as their colleagues simultaneously. Online, both tutor groups had similar levels of contact with their colleagues; this meant an increase in contact for WSU tutors and a decrease for their UCD counterparts.

Student-tutor contact also both increased and decreased, depending on the circum- stances. Some tutors noted a lack of rapport with students and being more "business-like". In contrast, other tutors reported students wanting to stay on and chat about other aspects of university life. This may be due to students' lack of peer interaction, the fact that they did not present as much to online MSS in groups and the individual nature of online learning.

For their part, students working in groups in online MSS reported a subdued atmosphere, affected by their peers' reluctance to contribute to public discussion or even allow themselves to be engaged. This was frustrating for some respondents, who felt that a seemingly sparsely populated learning environment diminished collaboration. The effect of this in limiting opportunity for socially-mediated learning (Johnson & Johnson, 1987) might have equity implications in favouring students better adjusted to self-regulated learning, for example (Protopsaltis & Baumi, 2019). They also described the benefits of being physically proximate to other students, and tutors, in in-person settings. Such benefits included stronger mental commitment, improved focus and – in the absence of technology-created distractions – deeper concentration and a sense of continuity through the lesson.

A related, striking, observation on this theme was the extent to which mathematical learning is social. Students admitted to being unaware, until COVID-19, of what was gained from their peers on campus in terms of the implicit or "accidental" learning that happens in this environment. This resonates with Meehan and Howard (2020), where students noted that they "missed the easy interactions with peers and lecturers that they enjoyed pre-COVID" and the "the negative impact this absence had on their learning" (p. 24). For mathematics educators forced to practice online, this presents a challenge. There is potentially much "hidden" or "osmotic" learning that happens in in-person con- texts, where complex and subtle social dynamics can aid students' alertness, concentration, commitment and readiness to learn. Such contexts also foster an open attitude to learning, where fellow students are recognized, present and available to offer peer support or simply human companionship. Opportunities should be created for students to interact informally online to replace some of the informal face-to-face contact, and recognize the value of social interaction in students' intellectual development (Sorensen & Donovan, 2017).

While obviously missing their peers and lecturers, students clearly appreciated the opportunity to talk directly to MSS tutors one-on-one. MSS is different to timetabled forms of learning due to its focus on personalized interaction, which is doubly valued by students in the online setting. Appreciation for tutors' enthusiasm and positivity was evident from students' reports. WSU students praised MESH workshops as one of the only places where they were permitted and encouraged to talk to each other. In general MSS has always been a highly appreciated student service but the limitations of online learning have brought this into sharper focus for the students.

5.6 Conclusion

In the COVID-19 era, much has been learned about what is possible in the realm of teaching, supporting and learning mathematics online. This study has shown that, despite the different circumstances of the two institutions, the impact of the pandemic-enforced move online on MSS tutors and students was largely similar. The themes of pedagogical changes, social interaction and student appreciation of MSS have all highlighted the shared desire among staff and students for connection and communication.

The one-on-one interaction that is a key feature of MSS was very much appreciated by students who came to realize the value of lost in-person peer-to-peer learning. Tutors struggled pedagogically due to the loss of non-verbal communication with students and the inability to see students' prior work or understand their questions due to technological issues. Moving forward, tutors' online pedagogical training and organization of peer-learning opportunities for students should be key priorities for MSS best practice. The benefits of on-campus interactions for tutors and students are clearly evident and can- not be overlooked in any institutional expansion of online MSS. This study has shown that in general these benefits were not replicated in the online setting enforced by the pandemic. Thus, as most higher education institutions intend to continue with some form of hybrid MSS post-pandemic (Hodds, 2020) further research is required to explore how this might be achieved.

Potential research questions stemming from this study include: is it possible to characterise optimal online MSS pedagogy?; if so, do MSS tutors have the necessary skills and access to relevant training to reach this level?; how can the peer-to-peer social interaction that is important to students and their learning, be addressed in online MSS? It will be important to monitor the aspects of MSS relating to pedagogy, social interaction and student appreciation as MSS develops post-pandemic.

In conclusion, this paper documents the experiences of MSS students and tutors during the early days after the rapid transition to online tutoring and learning. While the findings may not be surprising to MSS practitioners it is nonetheless important to highlight these issues to aid the future development of MSS.

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6 Optimising the blend of in-person and online support: the student perspective

Abstract

This paper explores the provision of online and in-person mathematics support from the student perspective by comparing and contrasting online, and in-person formats of mathematics support offerings from University College Dublin and Western Sydney University. Analysis of 227 student responses to six surveys is presented. Three surveys were conducted at each institution, based on students' use of mathematics support in both in-person and wholly online settings, and those who had used only online or only in-person support. Students rated the quality and importance of eleven support aspects based on their experience of online and/or in-person support and indicated their future format preference across a range of scenarios. Students' suggestions for improvements to both formats were also gathered. Results highlight the differences and similarities of the online and in-person experiences, with statistically significant differences between support formats found in four quality ratings, two importance ratings, and in seven of the ten questions on future format preferences. Findings suggest a hybrid model of support is desired by students in the future. The discussion of students' views presented will enhance practitioners' efforts in optimising the blend of online and in-person mathematics support.

6.1 Introduction

At the time of this research, Higher Education Institutions (HEIs) had emerged from campus closures (due to high COVID-19 infection rates) and were returning to on-campus learning and teaching. Evaluating what was learned from pandemic-enforced online learning environments is vital in optimising hybrid forms of learning. Evidence suggests that the vast majority of mathematics and statistics support (MSS) providers prefer in-person support but intend to continue to offer some form of synchronous online MSS that did not necessarily exist at their institution before the pandemic (Hodds, 2020; Gilbert et al., 2021). Campus lockdowns forced MSS to move online, resulting in a cohort of students who have now experienced both forms of support. In this paper, students' perspectives of MSS over almost two years of mostly online learning, will be synthesised to evaluate the potential of hybrid MSS—offering both online and in-person MSS concurrently.

The overarching aim of this paper is to support those coordinating and working in MSS to decide on the best blend of online versus in-person support in the future. It can be seen as complementary to the practitioners' perspective of online MSS (Gilbert et al., 2021), and a bookending to Mullen et al., (2021; 2022) where the experience of both student users and tutors using online MSS at two universities was explored. This paper is guided by students' experiences of MSS in both online and in-person formats prior to, during, and post-COVID-19 lockdowns, and thus informs the following research questions:

1. How do students differ, if at all, in their opinion of MSS provision based on the format used (online/in-person)?
2. What aspects of MSS are important to students and does this differ based on the format of MSS used?
3. Which format(s) of MSS do students prefer to use in different scenarios?
4. What, if anything, would encourage exclusive users of one MSS format to use the alternative, and how can both formats be improved for the future?

Relevant literature to aid the answering of these research questions is reviewed in section 5.2. Section 5.3 describes MSS at both universities, while the methodology is outlined in section 5.4. The results, discussion and conclusion are presented in subsequent sections.

6.2 Literature review

Given this is a follow-on study to Mullen et al., (2021; 2022), this literature review extends rather than rehearses the comprehensive literature reviews of Mullen et al., (2021; 2022) by considering a number of contemporaneous studies.

From articles of O'Shea (2022), Radmehr and Goodchild (2022), Reinhold et al. (2021), and Žnidaršič et al. (2022), it is evident that the rapid shift to online teaching and learning caused by

COVID-19 has forced a re-evaluation of online and in-person mathematics education. Perceptions among lecturers of the indispensable nature of in-person learning environments, for example, have not always aligned with achievement results that are equivalent across both modes (Žnidaršič et al., 2022). The favourable disposition of students towards many elements of online learning (enhanced flexibility, opportunity for self-paced study, provision of extra resources, freedom from campus commutes, etc.), and the momentum for a "new normal" that involves a mix of in-person and online experiences must be considered. Students have given mixed signals in what they desire and expect in a post-pandemic world. They want some online learning affordances maintained but a return to in-person environments for improved social connection with peers and physical access to teachers, simplified study routines, and structures, and "live" presentations of lectures and tutorials. (Radmehr and Goodchild, 2022; O'Shea, 2022).

It is arguable that the relationship between in-person and online teaching and learning has received more intense scrutiny in the COVID-19 era than at any other time since the emergence 30 years ago of internet-enabled learning. However, according to Radmehr and Goodchild (2022), agreeing with Trenholm et al. (2019), there remain questions of the maturity and adaptability of the online mode. Students and lecturers still face challenges working online, and advanced technologies can not yet replace the in-person experience. This could be affected by differences across the teacher-student or generational divides between usage behaviours and familiarity with relevant digital technologies and platforms (Engelbrecht et al., 2020). Indeed, in analysing the responses to 12 survey items probing student and teacher perceptions of the pandemic-enforced switch to online teaching and learning, Radmehr and Goodchild (2022) suggest that "many of the challenges students experienced were not anticipated or considered by the lecturers to be part of their responsibility" (p.18). Assuming such a disparity did exist—or to the extent proposed here—this might point to reasonable differences in the attitudes towards, and perceived value of, certain technologies and approaches.

Reinhold et al. (2021) point to students' self-regulation as "a key factor in their learning processes" and highlight a distinction between two clusters of tertiary mathematics students— those of more or less promising motivational and emotional inclination (related to "mathematics related interest, anxiety, self-concept, and work ethic"). Students with a more promising attitude operated at a higher academic level and yet wanted more in-person social interaction and less emphasis on online learning formats than their less promising counterparts. The study highlights the need to foster learning environments that not only support lower-achieving students but nourish the intellectual needs of higher-ability students striving for excellence.

Three years on from the initial challenge of trying to provide mathematics teaching and support online, assessment of what has been learned, and how the student experience of learning mathematics may be optimised in a hybrid world, is timely. From the special edition of Teaching

Mathematics and Its Applications: Restarting the New Normal, Gilbert et al. (2021) conducted a study of MSS practitioners at two time points, May 2020, and January-February 2021. The consensus from MSS practitioners was that in-person provision was the way forward in a post-pandemic setting. They concluded, however, that a significant minority of online provision will remain, such are its benefits. In July and August of 2020, Hyland and O'Shea (2021) sought mathematics students' perspectives at six universities in Ireland on the future of teaching and assessment post-COVID-19. Due to campus closures and subsequent forced moves to online learning, 56% of their respondents reported experiencing negative effects on their capacity to learn through their MSS services, with 43% stating they found it difficult to communicate with MSS services. In particular, Hyland and O'Shea (2021) report the increased similarity of teaching, tutoring and support delivery students experienced during lockdown. This led to a loss of peer interaction and peer learning that was provided for at varying levels across these delivery modes prior to lockdown.

The research presented in Mullen et al., (2021; 2022) revealed a significant drop in MSS usage from March 2020 to November 2020 in two HEIs, Western Sydney University (WSU) in Australia, and University College Dublin (UCD) in Ireland. Among the themes identified via qualitative analysis of 23 MSS tutors and student users in Sydney and Dublin were: the desire for increased social interaction between students; the mostly negative pedagogical changes incurred during the wholly online (lockdown) period; the idea that learning and tutoring mathematics online is different to other subjects; and thoughts on the future of online MSS. Students and tutors were open to the idea of hybrid MSS. This paper builds on that qualitative research by surveying students who used MSS services both pre-pandemic in-person and during the pandemic wholly online era, in addition to those students who used only one format of support exclusively, that is, either online only or in-person only. Students' opinions and preferences about hybrid MSS will be presented. How to act upon students' views and optimise the blend of online and in-person MSS in the future will also be discussed.

6.3 MSS at the two universities

WSU is a multi-campus university based in the western part of Sydney, Australia, with just under 50,000 students. MSS is available to all students, both undergraduates and postgraduates, and is offered on six campuses as well as online. Timetable and travel constraints make it difficult for students to attend a MSS service on a campus other than the campus where they are based. MSS services are provided by the Mathematics Education Support Hub (MESH). Services include drop-in support (usually one-on-one) and workshops in which students often work in groups facilitated by staff. In-person MESH drop-in services take place at a table in the relevant campus library with a MESH banner close by, and in-person workshops occur in classrooms. Online services, which began in March 2020, were available via Zoom; online drop-in help (four hours a day) and subject specific online workshops were offered. Online services have continued from March 2020 to present (December, 2021) with some in-person services being available depending on lockdown measures. At the time of conducting the survey MSS was only available online, but some in-person services (mainly workshops) had returned between August 2020 and August 2021.

UCD is predominantly a single campus university in Dublin, Ireland, with approximately 33,000 students. The Maths Support Centre (MSC) offers MSS to preparatory, first, and second-year undergraduate students. Prior to the pandemic-enforced move to wholly online support in March 2020, the MSC was a drop-in (non-appointment-based) facility only, based in a dedicated room of the main campus library. Once online it became an appointment-based service, hosted through Brightspace Virtual Classroom and later via Zoom. Appointments of 30 or 60-minute duration could be booked during the wholly online period of March 2020 to May 2021. Hybrid MSS at UCD began in September 2021 allowing students to book either an online Zoom appointment or an in-centre appointment, with students also permitted to drop-in to the physical centre without appointment.

Figure 5.1 shows the formats of MESH and the MSC from August 2019 to November 2021, the timeframe of this study.

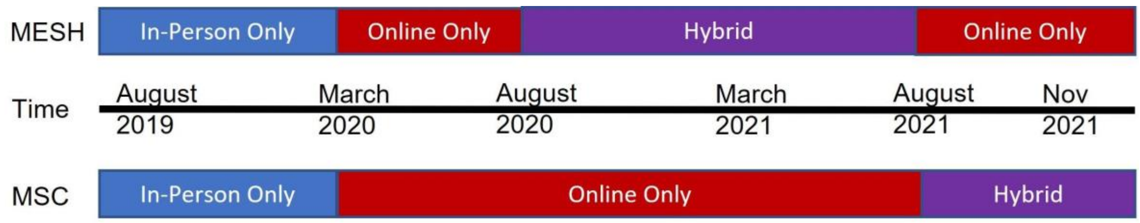

Figure 5.1: Timeline of various MSS formats at MSC and MESH from August 2019 to November 2021.

6.4 Method

An exploratory sequential mixed methods approach (Cresswell, 2014) was used to study various aspects of online and in-person MSS from both student and tutor perspectives. The results of the qualitative study presented in Mullen et al., (2021; 2022) are now complemented by a mostly quantitative study capturing data from a larger number of students. The three student groups, A, B and C, for the current study were identified as follows:

- Group A consisted of students who had used both in-person and online MSS services
- Group B consisted of students who had used online MSS only but had the option of in-person MSS
- Group C consisted of students who had used in-person MSS only but had the option to use the online MSS during COVID-19.

Similar but distinct surveys were designed for each group, with the only difference being that for some questions group A were rating their experience of both online and in-person MSS, whereas group B were asked to rate online, and group C in-person MSS only.

To maximise survey response rates the number of questions and amount of open-ended questions were kept to a minimum. Survey questions were designed by the researchers with guidance drawn from two sources: (1) findings of the qualitative study in Mullen et al., (2021; 2022) and (2) from an in-house UCD survey with 90 respondents from July 2020 of students who had used in-person MSS services from September 2019 to March 2020, and those who had used online support facilities from March to June 2020. The newly designed surveys were piloted several times among the researchers and colleagues to ensure clarity and minimise timing. The survey questions (which were hosted in Qualtrics) are available in Appendix G. A link to the survey was sent to students were via email with a reminder email sent two weeks later. At UCD, the survey was circulated in early September 2021 and closed at the end of October 2021. WSU students received the first email mid-October 2021 and their survey closed mid-December 2021. The survey was open for approximately seven weeks in both institutions. Ethical approval for the study was sought and awarded at each institution, and the plain language statement is available in Appendix H.

Table 6.1: Number of students in each survey group for each institution with numbers of respondents and percentage response rates in brackets.

	A: Both	B: Online Only	C: In-person Only	**Totals**
UCD	167 (26, 16%)	115 (15, 13%)	1,050 (104, 10%)	1,332 (145, 11%)
WSU	268, (16, 6%)	1,236 (40, 3%)	2,168 (26, 1%)	3,672 (82, 2%)
Totals	435 (42, 10%)	1,351 (55, 4%)	3,218 (130, 4%)	5,004 (227, 5%)

Table 5.1 shows the number of MSS users, for both institutions, that fit the definitions of the three survey groups A, B or C given earlier, that were invited to complete the appropriate survey. The number of responses and response percentage rates are shown in brackets. Low response rates may be due to a number of factors including: (1) the fact that 22% and 18% of group A respondents, 42% and 51% of group B respondents, and 51% and 56% of group C respondents were one-time visitors to MSC and MESH services respectively (group A students visited online once and in-person once), (2) UCD MSC users were also asked to take a similar survey for another unrelated study on MSS at the same time as this study, (3) WSU students were beginning their examination season, and (4) a number of group C's cohort were no longer MSS users due to lack of mathematics-related modules, or their stage of study, and therefore were less likely to respond. Additionally, several responses had to be deleted as respondents had started but not submitted the survey. Due to an ethics requirement, survey submission was how students consented for their responses to be included in the study.

All statistical differences presented in the results were identified using the Dunn test (Dunn, 1964) using the FSA package in R (Ogle et al., 2023) which adjusted the p-values using the Holm method (Holm, 1979). An alpha level of 0.05 was used throughout the analysis. Effect sizes were calculated using ε^2 (King et al., 2018) with corresponding confidence intervals (CI) are reported for each statistically significant difference. These were calculated in R using the rcompanion package (Mangiafico, 2023) and graphs were created using the ggplot2 package (Kassambara, 2023).

6.5 Results

The survey results for the student cohorts, group A (both), group B (online only) and group C (in-person only) will be aligned with the five dimensions identified in the qualitative analysis of Mullen et al., (2021; 2022), namely: *Usage of MSS*; *Social Interaction*; *Maths is Different*; *Pedagogical Changes*; and *Future of MSS* (the latter being renamed slightly to reflect the availability of in-person and online MSS). The first four themes contain results relevant to the first two research questions, and the *Future of MSS* theme links with the third and fourth research questions. How the various items of the survey correspond to these five themes is shown in Table 5.2. Note that "Importance of" before an aspect means that the students were first asked to rate a particular aspect of MSS and then rate the importance of that aspect to them, for example, rate the quality of learning environment and then rate the importance of quality of learning environment. An asterisk (*) denotes that the aspect or its importance had a significantly different rating between the survey groups (not the institutions). Two asterisks (**) denote that there were significant differences between the institutions in one or more of the survey groups, and also between the survey groups.

*Table 6.2: Survey items organised by theme. * indicates the item responses had statistically significant differences between survey groups. ** indicates statistically significant differences between survey groups and institutions.*

Usage of MSS	Maths is Different	Pedagogical Changes	Social Interactions	Future of MSS
Quality of help	(Importance of*) Access to required technology	(Importance of) Quality of tutoring	(Importance of) Quality of interactivity with peers*	Choice of MSS format in different scenarios*
(Importance of) Quality of learning environment**	(Importance of) Ease of verbally describing mathematics	(Importance of) Quality of one-on-one attention		Persistence and MSS format*
(Importance of) Convenience of times and locations**	(Importance of) Ease of writing mathematics*	(Importance of*) Usefulness of learning resources		Future access format choices*
(Importance of) Clarity of how the service operates				Improvement and attractive factors for both MSS formats

Results from UCD and WSU will be presented together unless responses were statistically significantly different. Firstly, the overall mean ratings of MSS aspects and their importance, listed in the first four themes, will be summarised. Secondly, differences and similarities of these ratings between the three survey groups and, if applicable, the institutions, will then be presented via the four themes. Finally, the results associated with the *Future of MSS* theme about students' format preferences, and suggestions to improve the attractiveness and appeal of both formats will be presented.

In order to rate the quality, convenience, clarity, access, ease, or usefulness of the eleven aspects listed under the first four themes, students were asked to choose one option from Very Good, Good, Neutral, Poor, Very Poor or N/A (Not Applicable) for each, except for Quality of help which did not have the N/A option. Students in group A rated online and in-person MSS separately for each aspect. The mean rating was calculated by converting Very Good to 5, Good to 4, and so forth. Similarly, to rate the importance of the ten aspects, students were given a five-point scale from 1 being Not Important to 5 being Very Important.

Overall, for both aspects and their importance, the mean ratings were high. Most rounded to a 4, meaning Good or Important, with three ratings rounding to a 5, meaning Very Good or Very Important. There were a few exceptions, namely: groups A and B rated *quality of interactivity with peers* online 3.03 (SD=1.22) and 3.70 (SD=1.07) respectively; group A rated *ease of writing mathematics* online 3.73 (SD=1.26); the WSU students in group C (in-person only) rated *quality of learning environment* 3.84 (SD=1.14) and *convenience of times and locations* 3.60 (SD=1.00); and finally, the three groups rated the *importance of quality of interactivity* with peers 3.62 (SD=1.16) (A), 3.64 (SD=1.18) (B) and 3.30 (SD=1.39) (C) respectively. A rating of approximately 3 indicates Neutral quality or Somewhat Important. Thus, the majority of respondents gave positive ratings for the given aspects of MSS and their importance, confirming that, regardless of MSS format, students mostly experienced high-quality support that they valued. The full set of mean ratings are available in Figures I1, I2, and I3 in Appendix I. Differences and similarities in ratings between survey groups will now be discussed by theme.

6.5.1 Usage of MSS

The four aspects of MSS that comprised the *Usage of MSS* theme are: *quality of help*; *quality of learning environment*; *convenience of times and locations*; and *clarity of how the service operates*.

There was a significant difference in how WSU and UCD respondents rated the quality of learning environment ($p=.005$, $\varepsilon^2=0.12$, CI=0.07, 0.23) and the *convenience of times and locations* ($p=.024$, $\varepsilon^2=0.09$, CI=0.05, 0.18) in group C (in-person only), with UCD respondents giving a higher rating than their WSU counterparts for both aspects. This could be due to the differences in how MSC and MESH operate. MESH in-person sessions are spread over several campuses, making them less convenient than UCD's one campus operation. Unlike UCD, MESH does not control the spaces used and cannot optimise them for student learning.

Though the MSC on-campus space is more controlled, UCD students who had experienced both formats of MSS rated the quality of the online learning environment higher than the in-person learning environment. Students in group A had a mean rating of 4.27 (SD=1.12) for quality of online MSC learning environment and 4.05 (SD=0.85) for the in-person MSC environment. Both of these ratings were lower than the high rating of 4.60 (SD=0.71) given by UCD's group C, with group A's rating of *quality of learning environment* for in-person MSS being statistically significantly lower than group C (p=.027, ε^2=0.12, CI=0.07, 0.23). WSU students had a statistically significant difference between group A's high rating of online and group C's lower rating of in-person (p=.015, ε^2=0.12, CI=0.07, 0.23) with online preferred by group A who rated online 4.53 (SD=0.52), and in-person 4.09 (SD=1.22). As previously mentioned, WSU group C had one of the lowest mean ratings for *quality of learning environment*, 3.84 (SD=1.14), a contrast to UCD group C's high 4.60 (SD=0.71).

For *convenience of times and locations*, WSU's group C rating of in-person MSS was significantly different to WSU's group A rating of online support (p=.008, ε^2=0.09, CI=0.05, 0.18). WSU students found the online times and locations significantly more convenient than the in-person times and locations, likely connected to WSU's multi-campus nature. MESH offers many more online hours than in-person hours for each campus. UCD cohorts mostly agreed about the convenience of the MSC's times and location, giving it high ratings across each survey group.

For *quality of help*, *clarity of how the service operates*, and the three Importance ratings of this theme, there were no statistically significant differences between institutions or survey groups. This means UCD and WSU MSS are similar in how their students rated *quality of help*, *clarity of how the service operates*, and how important they find *quality of learning environment*, *convenience of times and locations*, and *clarity of service operations*, whether accessing online or in-person MSS. Both *quality of help* and *clarity of how the service* operates were rated highly with over 70% of respondents giving the two aspects Good or Very Good, independent of survey group. Similarly, over 80% of each of the three student groups rated *quality of learning environment*, *convenience of times and locations*, and *clarity of service operations* as important or very important.

6.5.2 Maths is different

The *Maths is Different* theme highlighted three issues specific to how mathematics is different to other subjects: *access to required technology*; *ease of verbally describing mathematics*; and *ease of writing mathematics*. The importance of these aspects came to light in the move to online MSS where both tutors and students, but especially students, had constraints imposed on their mathematical communication caused by, for example, the limitations of the QWERTY keyboard. It is therefore surprising that all three survey groups, regardless of institution, had no significant differences in how they rated their access to technology and ease of verbally describing mathematics, as lower ratings from online groups were expected here. The only aspect which had significant differences between groups was ease of writing mathematics. There were significant differences among multiple group's ratings with group A's rating of in-person being significantly higher than all three other ratings, that is, group A's rating of online (p=.027, ε^2=0.17, CI=0.01, 0.27), group B's rating of online (p<.001, ε^2=0.17, CI=0.01, 0.27), and group C's rating of in-person (p<.001, ε^2=0.17, CI=0.01, 0.27). Also, group A's rating of online *ease of writing mathematics* was significantly lower than group C's rating of in-person (p=.002, ε^2=0.17, CI=0.01, 0.27). This suggests that group A, who experienced both formats of MSS, found it significantly more difficult to write mathematics online compared to their and others' experience of in-person MSS. Also, they found writing mathematics in-person significantly easier than their own experience online, others' experience online and others' experience in-person.

In rating the importance of *access to appropriate technology* and the *ease of writing* and *verbally describing mathematics*, the only significant differences between survey groups was in the importance of access to technology. Students in group C who had only experienced in-person MSS gave a significantly lower rating than those who had only experienced online MSS (group B) (p<.001, ε^2=0.11, CI=0.04, 0.20). Those who experienced both MSS formats had an importance rating in the middle of these two ratings showing how access to technology is more important to students using online MSS. The other two aspects—ease of writing and verbally describing mathematics—were rated close to Very Important by all students regardless of MSS format experience.

6.5.3 Pedagogical changes

Quality of tutoring, *one-on-one attention* and *usefulness of learning resources* were the three aspects drawn from the *Pedagogical Changes* theme. *Quality of tutoring* and *quality of one-on-one attention* both had high quality and importance ratings with no significant differences between groups, meaning students, independent of MSS format, rated the tutoring and attention they received highly. There were also no significant differences between survey groups in the *usefulness of learning resources* rating. However, there were in the importance of the *usefulness of learning resources* rating. Group B found *useful learning resources* significantly more important than group C (p=.004, ε^2=0.05, CI=0.01, 0.12), highlighting a potentially greater desire or need for learning resources in online MSS compared to in-person.

6.5.4 Social interaction

Only one aspect, *quality of interactivity with peers* and its importance, falls into the Social Interactions theme and there was a significant difference in the quality rating between survey groups. Group A's rating of online *quality of interactivity with peers* is significantly lower, even compared to group B's rating of the same item (p=.010, ε^2=0.04, CI=0.01, 0.12). It is the lowest rated aspect. This is likely explained by group A's experience of in-person MSS where, according to these results, the *quality of interactivity with peers* is much higher. Thus, in comparison, online peer interaction must be unsatisfactory. Also noteworthy is that approximately 10% of each survey group chose N/A (Not

Applicable) in rating the quality of peer interaction indicating they perhaps did not experience any peer interaction in MSS or did not wish to engage with peers during support, and therefore did not rate it. The *importance of quality of interactivity with peers* rating stands out not because there are significant differences between the survey groups but because the rating is lower than all the other importance ratings across the three survey groups. The respondents did not place as much importance on peer interactivity–especially those who only experienced in-person MSS.

6.5.5 Future of MSS

The final theme consists of items exploring which MSS format students would prefer in different presented scenarios. The surveys asked whether students would persist with a question longer in different formats of MSS, what format(s) of MSS they would like to avail of in the future, and how to improve both formats of MSS in the future when MSS does not have to be exclusively online. Students were given the following eight scenarios to ponder: You are on campus and have a quick question (Campus Quick Q); You are on campus and have a complex question (Campus Complex Q); You are at home and have a quick question (Home Quick Q); You are at home and have a complex question (Home Complex Q); You want help from a particular tutor (Particular Tutor); You want help with specific mathematics or statistics software/app/computer program (Software Q); You want to access support with friends (With Friends); You have an assessment due soon (Assessment Soon). In each scenario the students were asked whether they would choose online or in-person MSS. The percentage of students in each survey group that chose *online* is shown in Figures 5.2 and 5.3. "Assessment Soon" and "With Friends" are shown separately as there are significant differences in how UCD and WSU students responded. An asterisk (*) represents a statistically significant difference between survey groups. The colours were added to aid the reader, with shades of blue representing lower percentages of respondents choosing online (thus an in-person preference), white showing an even split at 50%, and shades of orange representing higher percentages of respondents choosing online MSS.

Scenario	A: Both (n=54)	B: Online (n=42)	C: In-Person (n=130)
Campus Quick Q	23.81%	33.96%	19.23%
Campus Complex Q*	14.29%	13.21%	2.31%
Home Quick Q	88.10%	94.44%	89.92%
Home Complex Q*	66.67%	74.07%	50.77%
Particular Tutor*	42.86%	53.70%	16.15%
Software Q*	33.33%	41.51%	13.85%

Figure 5.2: Percentage of each survey group that would choose online MSS in each scenario listed.

Figure 5.2 suggests that in most scenarios in-person MSS is more desirable than online MSS with the exception being that if at home the majority of students will choose online MSS, particularly if it's a quick question. There is no significant difference between the survey groups' choices in that scenario. However, if at home with a complex question the students who have only experienced in-person MSS are significantly less likely to choose online MSS than those who have experienced only online MSS ($p=.011$, $\varepsilon^2=0.01$, CI=0.00, 0.07), with those who have experienced both formats leaning towards choosing online but not as strongly as those in group B. Similarly, if students are on campus they lean towards using in-person MSS, with no significant differences between survey groups for the quick question scenario. If it is a complex question there is a significant difference—those in group C are significantly more likely to choose in-person MSS (or not choose online) than both those in Group A ($p=.026$, $\varepsilon^2=0.02$, CI=0.00, 0.08) and group B ($p=.019$, $\varepsilon^2=0.02$, CI=0.00, 0.08). When wishing to speak to a particular tutor, and if they have a question about software, again group C are significantly more likely to choose in-person MSS than both group A (Particular tutor: $p=.002$, $\varepsilon^2=0.01$, CI=0.00, 0.05; Software question: $p=.021$, $\varepsilon^2=0.01$, CI=0.00, 0.06) and B (Particular tutor: $p<.001$, $\varepsilon^2=0.01$, CI=0.00, 0.05; Software question: $p<.001$, $\varepsilon^2=0.01$, CI=0.00, 0.06), highlighting that group C, those who have only ever experienced in-person MSS, are choosing differently from the other student groups.

Scenario	A UCD (n=26)	A WSU (n=16)	B UCD (n=14)	B WSU (n=40)	C UCD (n=104)	C WSU (n=26)
With Friends	8.00%	75.00%	29.00%	58.00%	10.00%	38.00%
Assessment Soon*	46.00%	88.00%	50.00%	70.00%	11.00%	48.00%

Figure 5.3: Percentage of each survey group by institution that would choose online MSS in the given scenario.

Figure 5.3 presents the scenarios of "With Friends" and "Assessment Soon" as there are significant differences between WSU and UCD students' choices (With Friends: $p<.001$ between group As, $p=0.036$ between group Cs, $\varepsilon^2=0.09$, CI=0.04, 0.18; Assessment Soon: $p=.007$ between group Cs, $\varepsilon^2=0.02$, CI=0.01, 0.09). Therefore, these scenarios were analysed by institution and survey group. There are no significant differences between the three UCD survey groups or between the three WSU survey groups for "With Friends" but percentages indicate that the WSU students are more likely to choose online MSS than UCD students. For "Assessment Soon" there are significant differences between UCD groups but not WSU groups. The UCD in-person only group are much less likely to choose online MSS with an assessment approaching than those who have experienced only online UCD MSS ($p=.047$, $\varepsilon^2=0.02$, CI=0.01, 0.09), and those who have experienced both ($p=.010$, $\varepsilon^2=0.02$, CI=0.01, 0.09). Again, WSU students are more likely to choose online than their UCD counterparts.

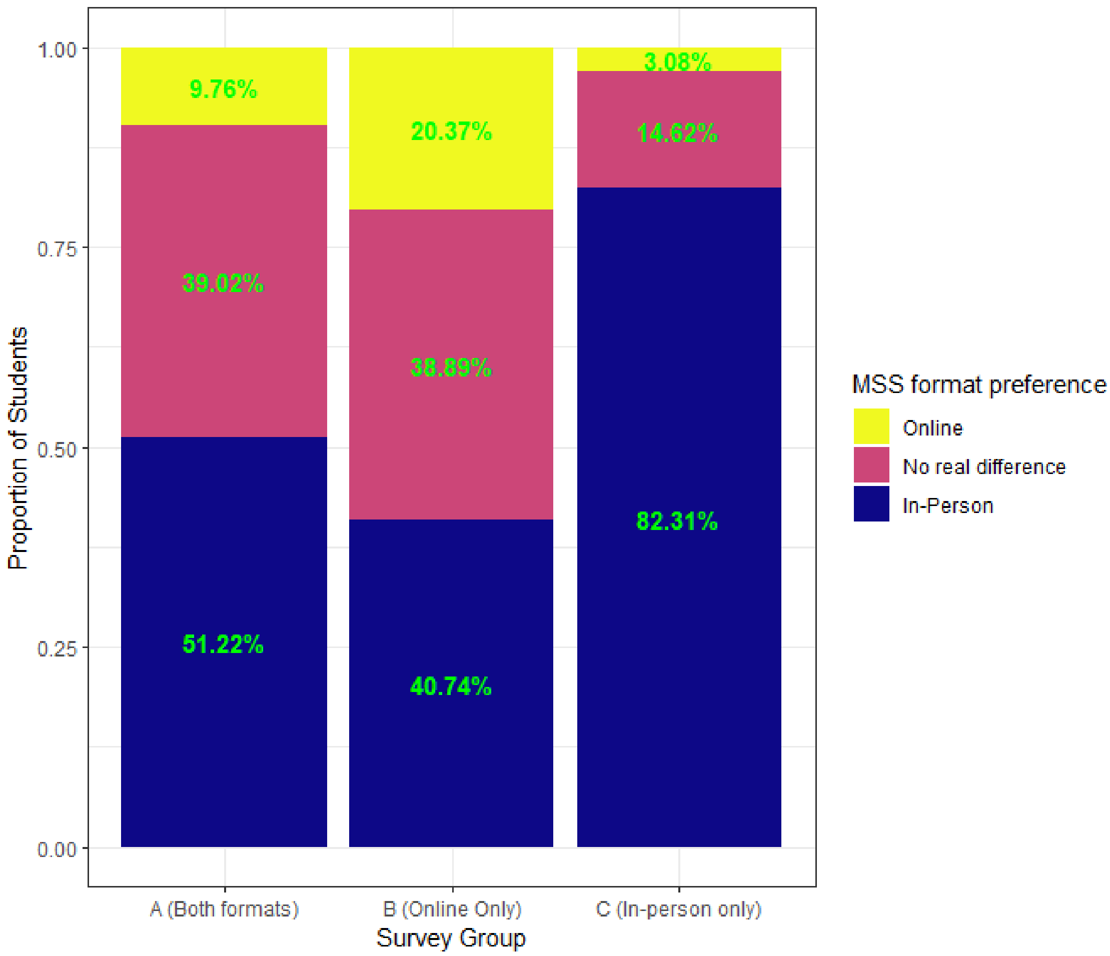

Figure 5.4: The formats of MSS in which each survey group is more likely to persist with a problem.

Important factors in mathematics success are perseverance and resilience (Lee & Johnston-Wilder, 2017). Therefore, students were asked if they were more likely to persevere with their mathematics or statistics problem during an online MSS session, an in-person MSS session or whether it did not make any difference. Figure 5.4 shows where each survey group would be more likely to persist with a problem. Group C (in-person only) have chosen significantly differently to group A (Both) ($p=.001$, $\varepsilon^2=0.01$, CI=0.00, 0.06) and group B (online only) ($p<.001$, $\varepsilon^2=0.01$, CI=0.00, 0.06) while group A and B are not significantly different to each other. Group C has a strong preference for in-person MSS as seen in the scenarios results, while the other two groups express a more mixed preference with a tendency towards in-person MSS.

Figure 5.5 shows how the students wish to access MSS in the future, with most wanting some sort of hybrid option (the red “Mixture of both” choice, the purple “In-person mostly”, and the orange “Online mostly”). Again, group C have chosen significantly differently to the other two groups (group A: $p<.001$, group B: $p<.001$, $\varepsilon^2=0.01$, CI=0.00, 0.06) with a clear preference for in-person support, while the others wish for a blend with the majority of students in the purple, red and orange segments. While there is no significant difference between the choices made by WSU and UCD students within each survey group, WSU students are more in favour of online MSS than their UCD counterparts.

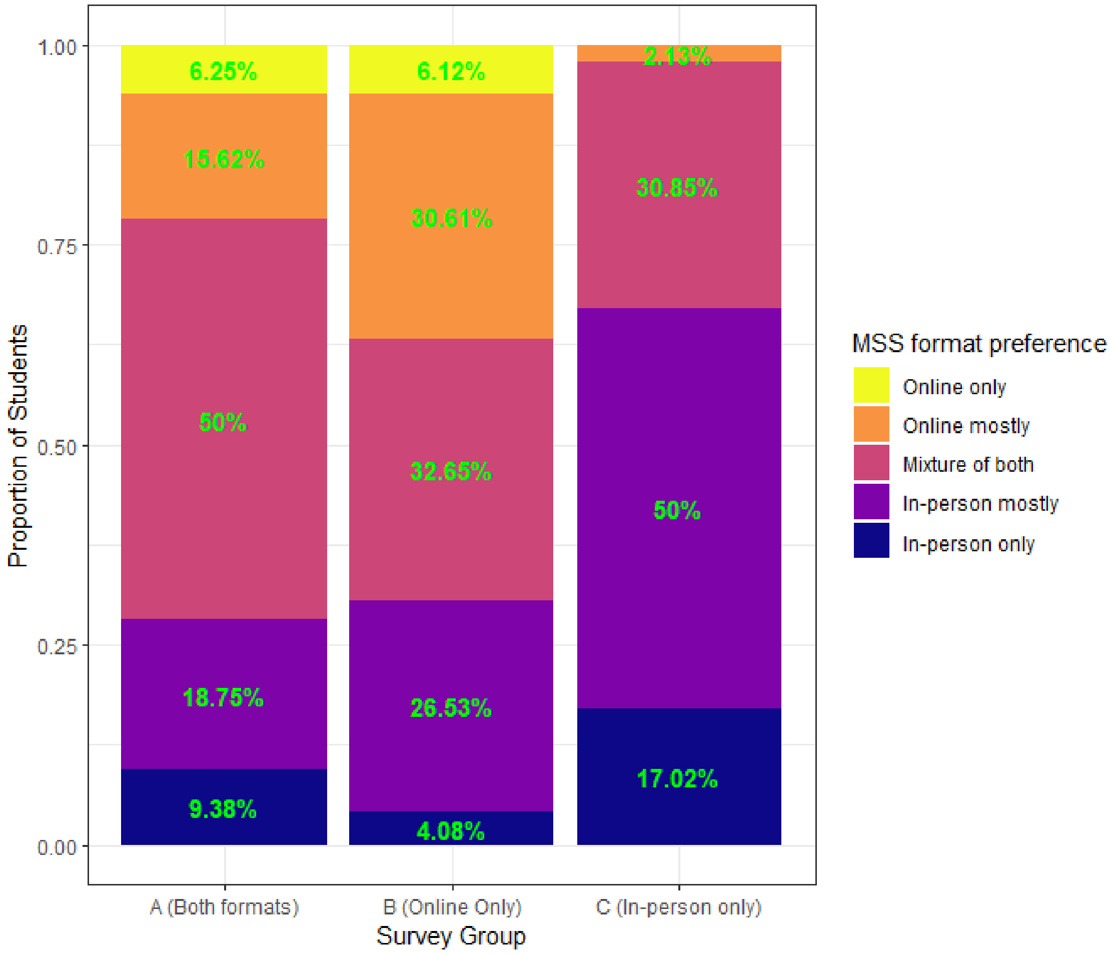

Figure 5.5: Future MSS format choices by survey group.

Near the end of the survey, students were asked to choose one item from a list of possible changes related to improving each MSS format or to give a different suggestion. This question was asked firstly for online MSS and then in-person MSS. For brevity, only the top two options selected by each survey group are presented in Table 5.3. For example, the second row, second column cell indicates that 69% of those who accessed both MSS formats chose “Timetable suitability” as the most important improvement to be made to online MSS. The different suggestions made, that were not listed in the survey, fell largely under the presented possible changes with no discernible themes arising.

In a bid to gain insights into how online users could be encouraged to use in-person supports and in-person users online supports, respondents were asked to choose the single most important factor that would render online/in-person MSS more attractive to them in the future. The top two choices for each survey group are presented in Table 5.4.

Table 6.3: Top two chosen improvements for online and in-person MSS by survey group.

Improvements	A: Both	B: Online only	C: In-person only
1st Online	Timetable suitability (69%)	Timetable suitability (38%)	Timetable suitability (24%)
2nd Online	Technology to write (13%)	Suitable learning environment (25%)	Suitable learning environment (21%)
1st In-person	More private consultations (31%)	More private consultations (25%)	More private consultations (35%)
2nd In-person	Timetable suitability (25%)	Timetable suitability (25%)	Less formal atmosphere (24%)

Table 6.4: Top two chosen factors that would make online and in-person MSS more attractive by survey group.

Attractive factors	A: Both	B: Online only	C: In-person only
1st Online	Technology to write (38%)	Suitable learning environment (36%)	Timetable suitability (27%)
2nd Online	If their travel time to campus increased (25%)	Timetable suitability (21%)	Technology to write (15%)
1st In-person	More private consultations (43%)	Timetable suitability (33%)	Timetable suitability (100%)
2nd In-person	If their travel time to campus decreased (43%)	Clearer guidance (28%)	

6.6 Discussion

As mathematics and statistics support practitioners continue to re-imagine their services in a post-pandemic world, this study offers insights into students' opinions of online and in-person MSS and their preferences. Echoing the findings of Mullen et al., (2021; 2022), students had a preference for in-person MSS services in the future (Figure 5.5), but there was a definite desire for a mix of both in-person and online MSS. Thus, the quality of both formats must be considered and, where possible, improvements made in order to aid the design of a hybrid MSS service. This reflects the belief of Hyland and O'Shea (2021) that tutorials and support services must be prioritised in future blended approaches to mathematics learning.

The first research question asked how students differ, if at all, in their opinion of MSS provision based on the format they have used. For both institutions student satisfaction with both the online and in-person support modalities is high, with quality ratings mainly being Good or Very Good. Only four aspects of MSS, of the eleven rated, had significant differences between how the survey groups rated them. These aspects were *Ease of writing mathematics*; *Quality of interactivity with* *peers*; *Quality of learning environment*; and *Convenience of times and locations*. The latter two aspects had significant differences between the two institutions in one or more of the survey groups which was not surprising due to the difference in campuses and MSS provisions of WSU and UCD, particularly in-person MSS services. The difference in opinion of the survey groups in the first two aspects highlights how writing mathematics is much more difficult online and interaction with peers is of a lower quality online (as found in Mullen et al., (2021)), two issues the MSS community were already aware of (Gilbert et al., 2021).

The significant difference in learning environment quality shows that UCD students who had experienced both formats of MSS rated the learning environment of in-person MSS significantly lower than those in group C who had experienced just in-person MSS. This is an interesting finding that should be taken into consideration as in-person MSC services have resumed—the in-person learning environment (a room in the main UCD library) is less preferable for some students once they experienced the online environment in a Zoom breakout room. This is most likely related to the noise that can be present with multiple MSS sessions ongoing in close proximity in the MSC in comparison to the privacy and confidentiality of one student and one tutor in a Zoom breakout room. WSU group A students also rated the quality of the online learning environment higher than the in-person learning environment, though this difference was not statistically significant. However, WSU group C, who had only experienced in-person MSS, had a mean *quality of learning environment* rating of 3.84 (SD=1.14)—one of the lowest mean ratings in this survey. This strong contrast between UCD and WSU's group C ratings of in-person learning environment quality is most likely due to the differences in the universities' on-campus provisions—a dedicated MSC space as opposed to multiple library pop-up MESH tables for drop-ins and classrooms for workshops.

Similarly, the significant difference in how WSU group C students rated the convenience of in-person MSS times and locations in comparison to group A's rating of online MSS highlights how WSU's multi-campus nature meant that a move to one online drop-in session from multiple in-person sessions in varying locations created a much more convenient MSS service. UCD students gave similar ratings for both online and in-person formats, reflecting the advantages of having one campus with one MSC. The amount of online versus in-person MSS offered should therefore take factors like travel time to campus into account. Indeed, these four statistical differences in rating of: *Ease of writing mathematics*; *Quality of interactivity with peers*; *Quality of learning environment*; and *Convenience of times and locations* all highlight practical differences between online and in-person MSS that must be considered, as both institutions move forward with hybrid MSS formats.

On the other hand, the lack of difference in the generally very high ratings of the other aspects suggests that regardless of MSS format, the MSC and MESH support services are highly valued. This was somewhat surprising given tutors' concerns about the quality of help they were providing as reported in Mullen et al., (2022). Perhaps this was due to the newness of online support for many MSS practitioners and the extra effort expended to make it work, or perhaps students were just very grateful for the online support. This aligns with previous research purporting students regard the quality of tutors as the most important factor influencing the effectiveness of MSS offered (Lawson et al., 2003). Some lack of statistically significant differences were surprising, in particular for *ease of verbally describing mathematics* as lower ratings from the online groups were expected given difficulties described by students and tutors in Mullen et al., (2021). These students may not have verbally described mathematics in-person before, which many believe is easier, and so see what they have experienced as normal quality. Or, perhaps students accessing MSS online have become more accustomed to verbally communicating mathematics, a potentially unexpected positive effect of the enforced online learning format. However, the difficulty with writing mathematics online still persists.

Examining the second research question, the generally high, mostly similar ratings across groups on the importance of the different aspects of MSS are perhaps unsurprising as they are key aspects of an effective MSS service based on the previous study (Mullen et al., 2021; 2022), and students recognised that. Thus, the lower importance rating for the quality of interactivity with peers is of note. Students across the survey groups placed lower importance on interacting with their peers in the MSS setting whether they had experienced online or in-person. This contrasts with the previous finding of Mullen et al., (2021; 2022) where students missed peer learning—though they never explicitly said they missed peer learning in the MSS context. Perhaps these students had not experienced peer interaction in the MSS setting and therefore underestimated its value as previous studies have highlighted how MSS can build communities (Gilbert et al., 2021; Hyland & O'Shea, 2021; Solomon et al., 2010). Perhaps these students did not desire peer interaction in the context of receiving MSS and simply wanted to consult with a tutor. It must be acknowledged that the existence or extent of peer interaction is also a function of the support conditions and facilitation on offer. How peer interaction occurs or does not occur in hybrid MSS will be interesting to observe.

The significant differences in importance ratings of *Access to required technology* and *Usefulness of learning resources* highlight how online support is different to in-person MSS. A student needs some form of technology to use online MSS whereas in-person MSS can be achieved with just pen and paper. Therefore, group C's lower (M=3.56, SD=1.25) rating is understandable. Tutors online found it easier to recommend learning resources by simply copying and pasting a link and students potentially used more learning resources online. In contrast, in-person students may not have encountered resources like worksheets or videos as much due to lower visibility or accessibility during a MSS session. However, learning resources were still rated important by group C. There were no mean ratings below 3 (moderately important), indicating that all aspects of MSS identified were important to students.

For current and future planning of MSS, the third research question asked students which formats of MSS they preferred, when they would access each format, which format would help them persist with a problem, and which format(s) they would like to access in the future. Analysis of these questions suggested a tendency for students to go with what they know—group C who had not experienced online MSS opted, often significantly, to choose in-person MSS more than groups A and B who were more open to using online as well as in-person, or preferred online MSS. This was to be expected as, though not significantly different, the WSU students were more in favour of online than UCD students. WSU's multi-campus nature and corresponding travel difficulties makes online MSS more attractive due to its convenience. Also, WSU students and tutors have more experience with online MSS than their UCD counterparts due to the different timings of semesters, and how they aligned with COVID-19 lockdowns. Surprisingly, when it comes to persistence, over 40% of group B, who had not experienced in-person support, felt they would be more likely to persist with a problem in-person, showing more of a similarity in opinion to the other groups than in the scenarios questions. This raises the question: does what is best for students' learning align with what they claim to prefer? It will be interesting to see how new students at both universities, with experience of neither MSS format, will choose in the future.

Therefore, what actions can MSS coordinators and tutors take to ensure the best possible support experience for their students in the future? The results from the *Future of MSS* theme indicate that a hybrid MSS service is desired, and similar findings, though in the broader university context, have also been reported by Radmehr and Goodchild (2022) and O'Shea (2022). Therefore, improving both online and in-person MSS is of interest and leads to the fourth research question. When asked to suggest improvements, the foremost suggestion from all three survey groups relating to both online and in-person MSS was the same: *timetable suitability* for online MSS and *more private consultations* for in-person MSS. *Timetable suitability* was also an improvement suggested for in-person MSS provision by groups A and B, while group C's second suggestion was a *less formal atmosphere*. For other online improvements groups B and C suggested a *more suitable learning environment* while group A asked for *technology to write*. Some of these improvements are items MSS providers will already be focusing on and experimenting with: how to timetable online and in-person MSS together in a user-friendly, financially viable way. Timetabling was found to be an engagement issue during lockdown-enforced online-only MSS at Maynooth University, Ireland (Mac an Bhaird et al., 2021) and has previously been offered as a reason for non-engagement with in-person MSS (O'Sullivan et al., 2014) so is still worthy of consideration. Ways to provide for private consultations in-person will take some planning as both universities' MSS provisions' in-person services are in library spaces, the MSC in a room and MESH at a free table, which are currently not very private. This suggestion links with the differing opinions on the *quality of learning environment* discussed earlier. *Suitable learning environments* online, and provision of *technology to write* are both improvements that will be more difficult to implement as both are quite dependent on the student's location when attending online MSS and the equipment they have available to them. Neither of these factors are necessarily within MSS practitioners' control. Similarly, of the suggestions the survey groups made to make online MSS more attractive, maybe only *timetable suitability* is within practitioners' scope for change while the suggestions of *timetable suitability*, *more private consultations*, and *clearer guidance* could all be acted upon to make in-person MSS more attractive to students. In-person MSS is perhaps easier to manage and is preferred by practitioners, as discussed in Mullen et al., (2021; 2022) and Gilbert et al. (2021), but as shown in this paper, some online support is desired by students. Therefore, while it may be impossible to provide a hybrid MSS service that suits every student perfectly, these suggestions, along with the results of how the students would choose between formats of MSS, should help guide MSS provisions as hybrid MSS continues.

At time of writing, December 2022, both institutions had implemented a hybrid format of MSS to varying degrees of success. Student attendance numbers were improving in both the MSC and MESH from their pandemic-affected lows reported in Mullen et al., (2021; 2022). The usage of online versus in-person MSS is changing week to week and seems very dependent on students' contexts, but both types of MSS are being used. For example, the provision of online MSS at UCD fell from 25% in September 2022 to 15% in December 2022 due to lack of demand, with online bookings accounting for just 3.5% of all visits for the autumn semester of 2022/23. However, the results of these surveys align with our current experience: hybrid MSS is welcomed and used by students.

6.7 Conclusion

As the hybrid blend of in-person and online MSS continues to develop, this paper offers insight into students' opinions of both MSS formats and their preferences for the future. Independent of the MSS format used, UCD and WSU students had largely similar views on the quality and importance of various aspects of MSS they had experienced. The differences found highlighted the now well acknowledged (Gilbert et al., 2021) difficulties of online MSS, particularly the loss of peer interaction and the difficulty of writing mathematics well online, and therefore the importance of access to technology. However, peer interactivity was not deemed as important as other aspects. The benefits of online MSS were also presented: learning resources were found to be more useful to online users. With the large variance in ratings of the quality of the in-person learning environment and suggestions to have more private appointments available in person, the privacy of online MSS still seems to be appreciated, especially by UCD students. Students at WSU appreciate the convenience and flexibility of online MSS. With benefits of both formats recognised, students would prefer to have both online and in-person MSS available in the future. A preference for in-person was notable, especially among those who had not used online MSS, but based on these survey results a hybrid MSS provision should be planned for.

What exactly a hybrid MSS provision is, will be different for each institution. MSS practitioners will need to take their institution's and students' unique circumstances into account in the same way as UCD and WSU's differing in-person provisions have been considered here. Students want both online and in-person MSS available to them, so this should be provided where possible, and closely monitored as students adjust to the evolving hybrid university life. Just as it did during the past few years of lockdowns, MSS must continue to adjust to its current students' needs and one of the ways to do that, based on this study, is offering both online and in-person MSS, considering the scenario-based preferences for each format.

While limited by response rates, the research presented here reaffirms previous research in the area and presents new insights into how students may use MSS in the future. More research is required in this ever-changing space, looking at how students act and learn in established hybrid MSS provisions, how non-users are (or are not) affected by both online and in-person MSS being offered, and how tutors feel about the effectiveness of hybrid MSS. How other MSS provisions provide hybrid MSS, if at all, is also of great interest. Online MSS is still relatively new and blending it with in-person services for the optimal student experience is creating an exciting new era for MSS.

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7 Promoting student support engagement: The design evolution of MathsFit, a diagnostic and support programme

Abstract

To combat the drop in mathematics support engagement and in anticipation of additional student mathematical struggles due to school closures MathsFit, a mathematics diagnostic and support programme for first-year non-specialist students was designed. MathsFit features a three section diagnostic quiz assessing the fundamentals of mathematics, the results of which trigger a personalised feedback email for students suggesting support engagement and a second attempt at the quiz, if necessary. Support suggested includes a specifically designed online refresher course with videos and practice questions aligned to the quiz's content in addition to engagement with the Maths Support Centre. This paper charts MathsFit's development over three design iterations during 2020-2022 with 3,268 student participants from five mathematics modules. Insights from student surveys and interviews about participants' experience of MathsFit aid discussion of how MathsFit supports students. Analysis of MathsFit quiz results reveals how MathsFit identified students' mathematical weaknesses in Algebra and Functions and Calculus. Comparison of MathsFit engagement and quiz results showed differences between participants due to prior mathematics results among other demographics. The role of MathsFit within the broader university experience will be discussed highlighting the advantages and disadvantages of the current design. Future development of MathsFit will also be considered.

7.1 Introduction

As higher education institutions (HEIs) broaden their access routes to undergraduate programmes, the well-acknowledged issue of transition, particularly to university mathematics (Hochmuth et al., 2021), must take account of the diversity of students' backgrounds and mathematical proficiencies. In Ireland, as in many other countries, mathematics and statistics support (MSS) is a well-established aid to students' mathematical transition (Cronin et al., 2016; Lawson et al., 2019). Diagnostic testing of incoming university students has been occurring for at least 30 years (Lawson et al., 2002; Hyland & O'Shea, 2022) and often leads to the identification of students at-risk of underachieving in mathematics courses with the objective of supporting these students as early as possible in their transition to university mathematics (Gillard et al., 2010; Ní Fhloinn et al., 2013). MathsFit is an action research project that aims to support first-year students through a hybrid mathematics diagnostic and support system. The research element seeks to study students' support engagement as a result of diagnostic testing and evaluate the impact of that support. This paper focuses on how and why MathsFit was designed and developed over the three academic years 2020/21–2022/23 using an action research methodology of cyclical critical reflection. This encompassed the use of learning analytics, student interviews, and student survey response data to continuously evolve and improve MathsFit, keeping students' needs as the focus. Thematic analysis of student feedback and statistical analysis of the MathsFit quiz results and student demographics will be presented in this paper based on data of 3,268 participants, representing 12 cohorts of students. Two cohorts participated in September/October 2020, five cohorts participated in September/October of 2021 and final five cohorts participated in September/October of 2022.

7.2 Motivation for MathsFit

The rationale for implementing MathsFit in September 2020 were numerous. Firstly, quantitative research conducted on visits to the UCD Maths Support Centre (MSC) from 2015-2019 showed that the majority of students attending the centre achieved higher grades in the courses they sought support for than their classmates who did not visit (Mullen et al., 2021). Conversely, those students who failed mathematics courses, particularly in the first semester of first year, typically did not attend the MSC or if they did it was often on only one occasion and late in the semester. The reduced use of the MSC during March-May 2020 was also of concern. Due to pandemic enforced lockdowns, the MSC moved fully online and though a similar service to the in-person format was provided with the MSC remaining open an additional week more than planned the number of student visits decreased sharply. This is further explored in Mullen et al., (2021; 2022). Therefore, it was conceived that new strategies to engage and support these under-performing students were needed beyond existing measures of advertising and promotion of the service. Secondly, given the significant and ongoing disruption caused by the COVID-19 pandemic on second-level students' mathematics education from March 2020 there was a concern among MSC management that the mathematical preparedness of incoming university students might not be as strong compared to pre-pandemic times. Establishing the mathematical proficiency of incoming students would be informative for students and teaching staff. Thirdly, given the disruption to state examinations and the delay in the collation and awarding of teacher calculated grades, university students started later than usual. This meant a reduction in instruction from 12 to 10 weeks. Combined with the fact that first-year university examinations could not proceed in the traditional fashion of proctored, in-person closed examinations and these students needed to be assessed within this same 10-week period, ensuring students did not access support too late was a concern. As there would be less time available for students to engage in support and potentially a higher concentration of mathematics learning to support, diagnostics identifying support needs and early advertisement of support was thought to be beneficial for students' efficacy of support use. Thus MathsFit was designed to identify students in need of early support intervention and provide multiple means of support.

7.3 Literature Review

The identification and support of students who struggle with their transition to university mathematics can take many forms but commonly are accomplished in Irish HEIs through diagnostic testing (Hyland & O'Shea, 2022a) and/or the provision of MSS through MSCs (Cronin et al., 2016). A diagnostic test consists of carefully chosen questions to reflect students' mathematical proficiency, usually at time of entry to university. Students considered "at-risk" are guided to MSS. In Ireland, diagnostic testing has been running for at least 27 years with studies published about the results of such testing (Gill et al., 2010; Ní Fhloinn, 2009) showing the benefit of it for teaching staff. Students' response to diagnostic testing has been generally positive once its purpose is made clear and useful feedback and support measures are available (Ní Fhloinn et al., 2014). Diagnostic testing is usually scheduled in the first weeks of students' university classes and may be unexpected, which can be anxiety-inducing for some students (Gallimore & Stewart, 2014; Gokhool, 2023; Ní Fhloinn et al., 2014).

Hyland and O'Shea (2022a) collected 12 diagnostic tests from 11 Irish HEIs in 2019, compared the content across the tests and to historical tests, and situated their findings within the research on diagnostic testing. The mean number of questions was 23 with a standard deviation of 7.8 and a range from 11 to 40 questions. Their findings also included categorisation of test content where most questions required basic arithmetic and algebra knowledge, with few questions requiring any more advanced mathematical understanding than that. Tests from universities and institutes of technology were not significantly different, and all of the tests were similar to older tests dating from the 1980s though featured more algebra and less advanced topics such as differentiation and log rules. Their concluding suggestion was the implementation of a shared diagnostic test or bank of tests across all Irish HEIs, noting that the loss of longitudinal data (a reason why some HEI diagnostic tests do not change) would be outweighed by the annual large numbers of students who would take this test(s). This standardisation of diagnostic testing has yet to occur. Furthermore, there have been no reports of mathematics diagnostic results from Irish HEIs from later than 2019.

Diagnostic testing has been the topic of more recent research abroad. In the UK, it has been in place as long, if not longer than in Ireland (Lawson et al, 2002). Coventry University, England have been conducting and researching diagnostic testing since 1991 with Lawson (2003) presenting results from 1991 to 2001. Hodds et al. (2021) reported on diagnostic testing in Coventry University between 2001 and 2017. Hodds (2021, 2023) provided two updates to those results, particularly with regard to the effect of COVID-19. Diagnostic testing at Coventry University first targeted students in "at-risk" courses who had historically struggled with mathematics. Nowadays, students from all courses with mathematical content take a diagnostic test with three forms of the test available: Higher, Intermediate, and Foundation. All three tests feature 50 multiple choice questions. Students choose between the correct answer, three distractors and an "I don't know" option without the use of calculators. These tests cover a range of topics including algebra, arithmetic, calculus, and trigonometry. Students are guided through their results letter to corresponding worksheets per topic, if necessary. Prior to 2020, the test was taken during the first week of university in a scheduled lecture or tutorial with a time limit of one hour. In 2020, the test moved online using Numbas, an mathematics assessment system, and Moodle, the virtual learning environment, with each of the five sections of the test having a time limit of 12 minutes. All students completed the test at home within the first few weeks of starting university. In 2021, the test was again hosted online but students could take it on campus at a set time or, if unable to attend, at home. The test was hosted on Wiseflow, an assessment platform with a lockdown browser, to prevent cheating. The quiz topics and questions did not change, for comparison reasons, but the format of the Coventry University diagnostic tests has been adjusted, at least twice, due to COVID-19.

A similar initiative has taken place at the University of Edinburgh, Scotland since 2011, though the 20-question diagnostic test is hosted on the online mathematics assessment programme STACK (Sangwin, 2013). Students are given 90 minutes to complete the test on core high school mathematics topics and the results are used to recommend which first-year mathematics modules (high school level or more advanced) a student should take. A larger difference between Coventry and Edinburgh universities' tests is that the questions are reviewed and revised in the University of Edinburgh (Kinnear, 2018). Akveld and Kinnear (2023) detailed how to improve a diagnostic test via item response theory using the University of Edinburgh and ETH Zurich's diagnostic tests. The latter test is based on high school topics needed for the mathematics module that students will study as no state standardized examinations exist at the end of secondary school education in Switzerland.

Students choose between four to six answer options as well as "I don't know" as they may not have learned some of the content. A bridging course was developed as the follow-up support to the ETH Zurich test.

A German government-funded diagnostic testing system MINTFIT (Barbas & Schramm, 2018) also links to bridging courses. MINTFIT consists of a two part, 36-question test hosted on Moodle using the STACK testing system that was designed based on the cosh catalogue (Cooperation Schule-Hochschule, 2014)—a set of mathematical competencies German universities in Baden-Württemberg have accepted as the minimum standard that should be attained pre-university by Science, Technology, Engineering and Mathematics students. MINTFIT awards medals to students and recommends topics to review, with the availability of a breakdown of test results per topic that has between zero to four stars per topic based on students' results. The online bridging courses it connects to (OMB+ and viaMINT) serve students from multiple universities.

As is clear from these examples, there are (at least) two parts of diagnostic testing that necessitate sound learning design principles—the mechanics of the test itself, and the follow up support (Hawkes & Savage, 2000). The format of test questions, whether they are multiple choice, open answer or another type, changes how students work and what data may be gathered from their answers. Multiple choice questions mean the building of alternative answers, often based on common misconceptions, and students' choices allow easy analysis of incorrect answers. Open questions, if asked on paper, allow the collection of individual student's mathematical workings, and therefore insight into their mathematical reasoning. Marking design: deciding whether or not to use negative marking and how to spread the marks across questions must also be considered. Ní Fhloinn (2009) describes how negative marking was introduced in Dublin City University, Ireland to discourage guessing and gather information about which questions students would not attempt because of the negative marking. However, there are mixed reports on the effect of negative marking on certain populations, for example, related to gender (Funk & Perrone, 2016; Kacpryzyk et al., 2019). Other design decisions, including whether the test is paper-based or electronic, affect the efficiency of the marking process and the promptness of follow-up support.

In choosing the mathematical topics to be included in a diagnostic test, the mathematical expectations for students at university are communicated (Hyland & O'Shea, 2022a) and a connection to their previous mathematical learning made. Mathematical topics that tertiary-level students struggle with, identified through diagnostic testing or similar means, include solving equations and inequalities (Hyland and O'Shea, 2022b), "word" or application style problems (Tariq, 2008), simplifying algebraic expressions with indices (Ní Fhloinn, 2009; Hodds et al., 2022), and logarithms (Fitzmaurice et al., 2021). All four of these studies tested students on mathematical concepts included in secondary school syllabi.

Hyland and O’Shea (2022b) received 327 student responses from 10 Irish HEIs to their Algebra Concept Inventory and identified a high-achieving cohort of 199 students who had gained higher than average Leaving Certificate results. By studying that cohort’s answers, specifically the lowest scoring, Hyland and O’Shea (2022b) identified three questions, two about equation solutions and the other about an inequality solution, that indicated students’ lack of conceptual understanding of solving equations and inequalities. Via the inclusion of questions about how confident students were about their answers to each question, they identified a misconception among some students about the number of solutions an equation of the form f(x)g(x)=0 has, with students often considering only g(x)=0 but not both f(x)=0 and g(x)=0.

Fitzmaurice et al. (2021) provided broader results about Irish students' mathematical competencies via analysis of the University of Limerick’s diagnostic test results between 1997 and 2013. They studied pre-service mathematics teachers specifically. The 40-question diagnostic test covers arithmetic, algebra, geometry, complex numbers, calculus and word problems. Two questions about logarithms were consistently low scoring across the years. Fitzmaurice et al. (2021) focused on the worrying decline in results over the 17 years of data, with all but two questions showing a general decline in the number of correct answers per year. In particular, the logarithm questions, manipulation of formula question, and graphing a quadratic function question showed larger drops in the pre-service teachers’ performance.

While there are some differences between secondary school mathematics education in the Republic of Ireland and the UK, the difficulties mathematics students experience can be quite similar, thus, topics identified by diagnostic tests in the UK were also explored. Tariq (2008), not unlike Fitzmaurice et al. (2021), studied a specific degree grouping—bioscience students. Based on the results of a basic mathematics test of 20 questions administered to 326 students from seven universities in the UK, Tariq (2008) concluded that students struggled with “word” or application problems. The test was split into 10 abstract and 10 word problems and the mean results were 55% on the abstract questions and only 23% on the word problems, with 38.5% being the mean result for all 20 questions. More students tended to attempt the abstract questions with only 2% to 12% of the students not attempting the abstract questions compared to 11% to 75% not attempting the individual word problems. Within the abstract questions, students struggled most with calculating volume and surface area, while nearly all of the word problem topics were difficult for the students, especially questions about ratio, proportion, powers, and converting units. Analysis of students’ answers revealed confusion between multiplication and division, percentage misconceptions, order of operations errors, unit conversion misconceptions (this was also an issue in volume and surface area calculations), and misinterpretation of information presented in the word problem. One reason identified for these low results and many misconceptions was the wide range of students’ previous mathematics education. Some scored a C at General Certificate of Secondary Education (GCSE:

examinations completed at age 15-16) level while others earned an A in Advanced level (A-level) mathematics.

Hodds et al. (2022) focused only on students who received an A-level in mathematics when analysing the results from Coventry University's diagnostic test between 2001 and 2017. They presented a comparison of students' A-level mathematics results and diagnostic test results, splitting the students into those who achieved A*–C (60–100%) and those who earned a D or E (40-59.99%) in their A-level mathematics examinations. They briefly mentioned question topics that students struggled with. Four questions that were answered incorrectly by more than 50% of students each year in the D and E group were about simplifying an algebraic expression with indices, determining the partial fraction form of an algebraic fraction, determining the quadrant of an angle, and identifying the expansion of sin(A - B). There were no questions that were answered incorrectly by 50% or more of students every year in the A*–C group but the angle quadrant question fell into this category in 16 of the 17 years of data. Ní Fhloinn (2009), reporting on diagnostic testing in Dublin City University, also identified an indices question, particularly fractional indices, as poorly answered. Indices were highlighted as an area of extreme difficulty for students.

Ní Shé et al. (2017a) also looked for topics that university non-specialist mathematics students struggled with by using surveys. They surveyed 460 Irish university students and their 32 lecturers about the topics they thought were challenging for first-year students. Students identified using logarithmic laws and the connection between logarithms and exponents, finding limits, deciding if functions were continuous, finding stationary points, optimisation problems, and sketching graphs using derivatives as topics they were less confident about via closed Likert-style questions. Open question responses further highlighted students' difficulties with integration, differentiation, functions or graphs, logarithms and exponents, and limits. While the study asked about topics that are explicitly taught in first-year university mathematics, most topics should have been introduced in secondary school. All of the previous lists of topics except identifying continuous functions feature on the Higher Level mathematics secondary school syllabus but only differentiation, functions or graphs, stationary points, and optimisation are introduced at Ordinary Level (NCCA, 2015). Students who studied Higher Level mathematics in secondary school were, unsurprisingly, significantly less likely to identify problematic topics than students who studied Ordinary Level mathematics (via the Likert-style questions). The 32 lecturers in this study identified difficult concepts and difficult procedures and tasks for students separately. Difficult concepts identified by more than 10 lecturers were logarithms and exponents; formulae, equations, and symbols; and functions and graphing. The only difficult procedures and tasks item mentioned by more than 10 lecturers was the item formula, equations, and symbols.

Ní Shé et al. (2017b) also surveyed students and lecturers as to what resources they used/recommended to support their/students' learning in first year. The student responses fell into the following categories in order of the percentage of students who mentioned them, highest to lowest: lecture notes, books, tutorial notes, Khan Academy, YouTube videos, Wolfram Alpha, mathematics support, and Virtual Learning Environment (VLE). Lecturers' answers to the same question were: handouts, books, VLE, Khan Academy, mathematics support, GeoGebra, Screencast, Math is fun, and Wolfram Alpha. They also asked for suggestions about future resource development and both survey groups were in favour of online resources, despite the most recommended resources by both being paper based. Students desired video tutorials so they could work at their own pace, while lecturers sought interactive online resources with conceptual explanations and examples, and online quizzes for students. The authors noted the disparity between students' and lecturers' use of resources for mathematical understanding—students wanting more example solutions to mimic while lecturers wanted interactive unsolved exercises to make students think and practise to reach understanding. Both types of these desired resources have been included in the provision of follow-up support in reports about diagnostic testing (Burke et al., 2012; Sharma et al., 2019).

The main MSS measures in Ireland are conducted within MSCs. Most Irish diagnostic programs recommend visiting the MSC as follow-up support (Hyland & O'Shea, 2022a). These spaces, where students may drop-in or book an appointment to gain mathematics assistance are shown to impact students in a number of ways, as explored in Mullen et al. (2024). MSCs act as community spaces where students work together, and with more experienced mathematicians to aid their current mathematical and statistical learning potentially by revising previous mathematical and statistical learning. Mullen et al. (2021) showed increasing visits to the MSC were significantly related to improved final mathematics module grades. Thus, encouraging students to visit the MSC is an important factor in sustaining or contributing to student success, and one way to potentially achieve this is through diagnostic testing—the impetus for MathsFit.

How to communicate and ensure engagement with follow-up support is also a critical design choice. Lee and Robinson (2005) designed paired questions for their diagnostic test—two questions on the same topic. This allowed analysis of the paired questions to see if the same skill was examined and if the numbers of steps were the same, allowing interesting insights into students' mathematical processes and the design of the questions. However, engagement in follow-up support was not as high as desired, as students thought they had adequate knowledge of a skill when they answered only one of two questions correctly. Sheridan (2013) describes poor attendance at revision tutorials in what was Dublin Institute of Technology (now Technological University Dublin), Ireland. The average attendance was 11 students when 73 students were advised to attend after scoring less than 50% on the diagnostic test. Personalised and/or monitored support has a significant positive effect on students' engagement with offered support (Gallimore & Stewart, 2014; Burke et al., 2012). Understandably, students participate more when staff engage with them on a personal basis. Large online diagnostic systems with automatically marked multiple choice tests followed by a personalised, gamified online remediation course that allows immediate feedback and increased choice for students have also been successful (Sharma et al., 2019). Various types of follow-up support require different staff resources. Gamified systems do not require much staff-student interaction but the online course would need to be created or chosen. Ensuring diagnostic test results provoke action by both students and university teaching staff is the key theme across the literature on how diagnostic testing can aid students' transition to university mathematics.

Designing a long-term action research project in an educational setting has many considerations. A design focus on students means ensuring engagement and an inclusive provision of resources, and then gathering and using feedback to improve. There is little reporting about ensuring engagement from students in the diagnostic test, with most diagnostic tests like Dublin City University's (Ní Fhloinn, 2009), University of Limerick's (Fitzmaurice et al., 2019), and Coventry University's (Hodds et al., 2021) not having an incentive like assessment credit in place. However, these designs feature (or did feature) paper-based/in-class testing where students are "captive" and therefore participation was not difficult to ensure. Elsewhere, many reported online systems like the ones in the University of Edinburgh (Akverd & Kinnear, 2023) and the University of Illinois, USA (Ahlgren & Harper, 2011) are placement tests—the result determines which class a student will join and therefore students are obliged to participate. The assumption that students will participate in the initial diagnostic test is seemingly not debated in most diagnostic testing literature while the lack of student engagement in the follow-up support is frequently examined. As discussed, well-designed support with in-person monitoring/personalisation (Gallimore & Stewart, 2014; Burke et al., 2012) or online gamification (Sharma et al., 2019) have been successful in motivating engagement. For inclusive learning systems, the Universal Design for Learning guidelines suggest diagnostic assessment should not be a single written format and should include the collection of students' demographic information, school background, level of previous knowledge, personal characteristics, and students' interests. Any learning materials should be accessible, allow diversity, and have different types of interaction (Floretta, 2021). Naturally, communication with and feedback from should also feature in an inclusive environment (CAST, 2018). However, a representative sample of students' feedback can be difficult to obtain. Surveys are a common feedback collection method but response rates from students to surveys can be low (Nair et al., 2008), particularly online surveys (Nulty, 2008). Saleh and Bista (2017) explored graduate students' perceptions of why this is. They found participants' interests, survey structure, communication methods, and assurance of privacy and confidentiality impacted response rates. There are a range of strategies advised to improve response rates (Nulty, 2008) however, Fosnacht et al. (2017) suggest a high response rate may not be as necessary as believed. They found that the additional work in trying to increase an initial response rate may have a negligible effect on the results of the survey. Additionally, Hendra and Hill (2019) found little relationship between survey nonresponse bias and response rates. Nonetheless, surveys for students must be well-designed—easy to comprehend, time-sensitive, and well-advertised—to ensure the desired responses, both in answering questions as intended, and response rates. The collection of demographic information via surveys can aid diagnostic assessment (Floretta, 2021) and therefore are another design element to consider.

7.4 Design

An action research methodology of cyclical critical reflection using learning analytics, student interviews, and student survey response data was employed to design MathsFit. Figure 7.1 shows this cyclical process.

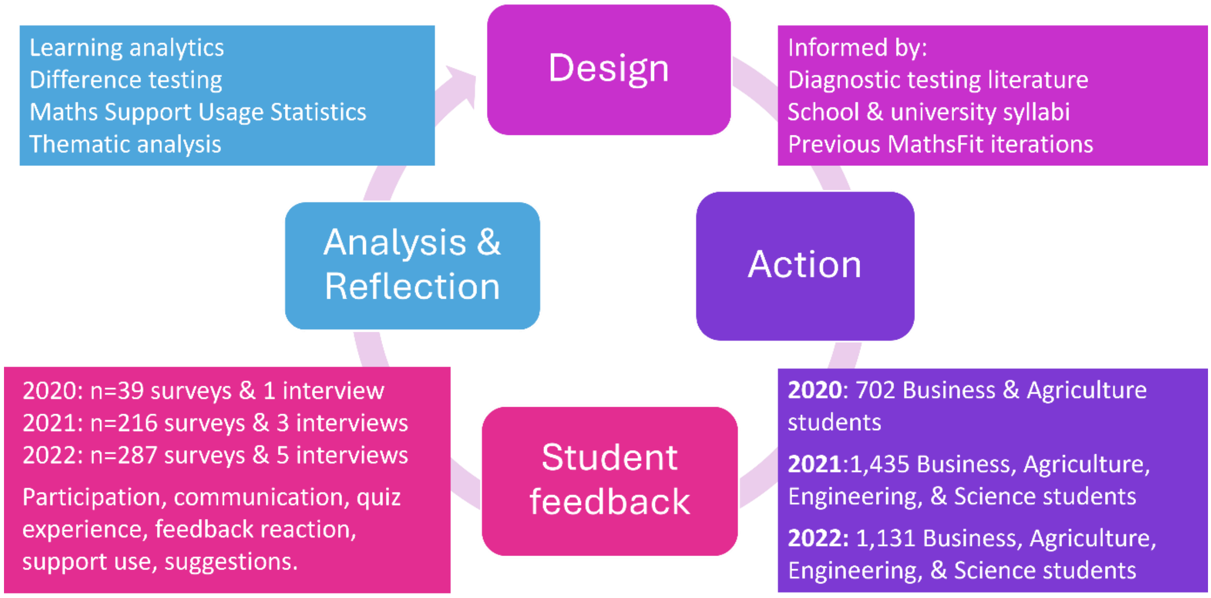

Figure 7.1: MathsFit's design-action-research cycle.

Over three cycles of MathsFit (2020, 2021 and 2022), the design and implementation of many aspects changed, prompted by student feedback and wider university issues. Major adjustments included: changing from online to hybrid design; implementing three different quiz and refresher course hosts, Brightspace (UCD's VLE), Numbas (an open-source e-assessment tool: https://www.numbas.org.uk/), and Bolster Academy (a commercial online learning and assessment environment: https://bolster.academy/); a reduction in the number of quiz questions; the removal of the quiz time limit; and the creation of four versions of the quiz, to allow for differences between participating modules. The Refresher Course also changed from post-quiz to pre- and post-quiz support. The evolution of each aspect of MathsFit will now be detailed.

7.4.1 Student participation

In 2020, MathsFit targeted two of the largest non-specialist mathematics modules taught by the UCD School of Mathematics and Statistics: Mathematics for Agriculture I and Mathematics for Business. For brevity, these will be referred to as module A and B respectively. In September 2021, MathsFit was extended to include three further first-year non-specialist mathematics modules: Calculus for Science, Introduction to Calculus for Engineers and Introduction to Calculus for Engineers NUin (the latter covers the same content and has the same instructor as Introduction to Calculus for Engineers but has a student population of solely American-registered exchange students). Henceforth these modules are labelled modules C, D, and E respectively. The Maths for Business (module B) and Mathematics for Agriculture I (module A) modules targeted in 2020, also continued to participate. In 2022, the five participating modules remained the focus of the MathsFit project. There was no change in their content, module coordinators or lecturers.

Every year students were sent an introductory email about MathsFit in the week before classes began which included a link to an introductory video welcoming them to the university and explaining the rationale and potential benefits of MathsFit. The Refresher Course was advertised in 2021 and 2022 as it was now available for pre and post quiz use. The video also notified students that MathsFit quiz results counted for up to 3.3% of continuous assessment credit for module B and up to 3% of continuous credit for modules C, D and E. Participation in MathsFit did not count for credit in module A per the module coordinator's wishes.

Students made their first quiz attempt during the first week of classes. During 2020, students were at home due to pandemic restrictions. In 2021 they completed the quiz on their devices in in-person tutorials. In 2022 they could start the quiz during in-person tutorials once the aims and purpose of MathsFit had been explained and they had accessed the Refresher Course, but most completed the quiz outside of class time. Tutorial slots in the first week had never been used by module coordinators before but were now timetabled for the students—an innovative part of MathsFit. Students used Brightspace to complete a pre-quiz-survey, three quiz sections and a post-quiz-survey. Students who had completed both surveys and the three quiz sections received a feedback email within 24 hours of their first attempt, with their quiz results and advice on support available (the Refresher Course and MSC engagement) based on their results.

The feedback email also notified students that they could make a second quiz attempt. In 2020 this was confined to a three-day period of the second week of classes. In 2021 and 2022 the second attempt was available either immediately, or the day after students made their first attempt, depending on what day of the week their tutorial occurred. It was recommended that students wait to hear their results via the feedback emails and participate in the support suggested before they attempted the quiz again. For the second attempt, there was no pre-survey and post-survey, and the students could choose which of the three quiz sections they wished to complete again. They then received a second feedback email with their updated results (the best of their two attempts per quiz section) and advice on using support throughout their time at UCD.

7.4.2 Quiz design

The design process began in August 2020 and students' first week of classes was in the last week of September 2020. There was only sufficient time to design one quiz, two surveys, the feedback process, and a simple refresher course consisting of videos and worksheets already created by the MSC. This was feasible as module A and B student cohorts commence university with similar mathematical prior learning standards and university entry requirements with B requiring slightly higher matriculation points and mathematics grades. A 30-question diagnostic quiz with three sections: Arithmetic and Trigonometry, Algebra, and Functions and Calculus was designed. Existing diagnostic tests from Ireland, the UK, and Australia were consulted extensively as well as the Irish Leaving Certificate mathematics syllabus (the state terminal second-level school examination taken by most school leavers in Ireland) and the syllabi for the two relevant university modules which had an overlap in content. The motivation was for students to reach mastery level in the basics of mathematics fundamentals. Questions were designed on the basis that the topics: (i) were included in the Ordinary Level Leaving Certificate course, (ii) would be required in the forthcoming university modules, and (iii) were assessed via a mixture of both procedural and conceptual questions. The 2020 version of the quiz is available in Appendix J. All but two of the questions were multiple choice with five options: the correct answer, three distractors (based on common misconceptions evidenced by literature such as Hyland and O'Shea (2022a)), and an "I don't know" option. Non-multiple-choice questions were included to avoid process of elimination type responses via the multiple choices offered. "I don't know" was included as an option throughout to discourage random guessing and to differentiate between students who made errors in their solution and those who could not approach the question. Partial marks were available, in the question(s) with two answer boxes, it was 1 mark per box and selecting "I don't know" was worth 0.5 out of 2 marks.

The 2020 quiz was delivered online through the Quiz feature of the university's VLE Brightspace, and students had 45 minutes (15 minutes for each section) to complete it. Brightspace was chosen as it was the university's VLE so students would be able to access it easily, and it had the Intelligent Agents and Release Conditions features which facilitated a personalised feedback process. However, Brightspace quizzes in 2020 did not have the ability to randomise the variables in the questions, meaning both quiz attempts would feature the exact same questions and every student would be completing the same quiz. As the quiz was online, and in September 2020, students were studying at home due to pandemic restrictions so they completed the quiz unsupervised. Therefore, in the introductory video students were advised that completing the quiz would benefit them by providing personalised support suggestions, and completing it honestly with no assistance from the internet or other sources would be most beneficial. They were also asked not to use calculators, as the questions, particularly in the Arithmetic and Trigonometry section, were designed to assess their mental arithmetic.

In 2021, four quizzes based on the original 2020 quiz were devised due to the different mathematical prior learning standards and university entry requirements of each module. Table 7.1 provides the Central Applications Office (CAO) points for each module per year (these are a conversion of students' Leaving Certificate results with maximum 625 points available) and the recommended Leaving Certificate mathematics grade. A core set of 14 questions remained common across all four quizzes. Module B students were no longer asked Trigonometry questions as that topic had no application to the module. Students from modules D and E were asked some Higher Level Leaving Certificate standard questions, for example, integration. Each quiz had 24 questions—eight questions per section, and the three sections were themed as in 2020: Arithmetic and Trigonometry (AT), Algebra (Alg), and Functions and Calculus (FC). The reduction in the number of questions from 30 to 24 was made as in-person tutorials were possible again when many pandemic restrictions were lifted in September 2021. However, tutorials were capped at 45 minutes duration instead of 50 minutes. It was planned that students would complete the quiz and both pre- and post-surveys in their first tutorial so the quiz taking 45 minutes, as it did in 2020, was not feasible.

Table 7.1: Leaving Certificate entry requirements for modules A, B, C, and D.

Module	**2020 CAO points**	**2021 CAO points**	**2022 CAO points**	**Recommended LC mathematics grade**
A	456, 531, 477[8]	454, 566, 531	400, 554, 510	H7/O6[9]
B	521*, 517, 545	555, 555, 573	554*, 544,566	H6/O2 (Min O3)
C	533	577	566	H6/O2
D	531	565*	577	H4

Discriminant and correlation analyses were conducted on the 2020 quiz answers so that the questions with the lowest discriminant indices and/or highly correlated with another question were removed from the 2021 version of MathsFit quiz. In other words, this process identified questions that the vast majority of students scored similarly on (discriminant analysis) and questions that were similar to each other (correlation analysis). Questions AT 1 and AT 2 were removed as they were easily answered correctly if a calculator was used, and the features of question AT 1 were covered in AT 5. Question AT 6 for module B students had a very low discrimination index so FC 6 was put in AT 6's place instead, allowing nine of the ten FC questions to be kept for module B students. AT 6 was

[8] The three sets of CAO points for module A denote the CAO points required for Agricultural Science, Human Nutrition, and Food Science respectively. The three sets of points for module B denote Commerce, International Commerce, and Business and Law requirements. The asterisk indicates that not all students with those points received a place on the course, the places for students with those points were assigned via a lottery.

[9] Leaving Certificate grades are given in bands of 10%. H7 represents 30%–39.99% at Higher Level and O6 represents 40%–49.99% at Ordinary Level, these are the passing grades in each level. H4 represents 60%-69.99%.

kept and FC 6 was deleted for module A students, as AT6 did had a higher discrimination index for these students. Question Alg 8 about complex numbers was not covered in either module's content and thus was removed. Questions Alg 9 and Alg 10 were both factorising questions so Alg 9 was removed as it had a lower discrimination index for both modules. Similarly, questions FC 7 and FC 8 were both polynomial differentiation questions, so FC 8 was deleted without loss of assessing that skill as it had a lower discrimination index for both modules. Figure 7.2 shows the average percentage mark, standard deviation of marks, and discrimination index for each of the 30 questions answered by module A and module B students in 2020, with module A results shown in black, and module B results in blue. The questions with an orange fill were deleted for both modules, while the questions in orange text were deleted from one module's quiz—AT 6 was deleted from module B's quiz and FC 6 was deleted from module A's quiz. Quiz questions from 2021 are available in Appendix J.

Question	Average Mark		Standard Deviation		Discrimination Index	
AT 1	78.41 %	81.96 %	40.65 %	38.41 %	45.57 %	41.85 %
AT 2	88.55 %	96.7 %	31.43 %	18.24 %	35.44 %	12.59 %
AT 3	87.15 %	95.12 %	31.64 %	21.28 %	30.38 %	10.37 %
AT 4	49.83 %	69.97 %	47.86 %	45.02 %	77.22 %	64.63 %
AT 5	49.91 %	63.87 %	38.86 %	40.59 %	56.65 %	61.11 %
AT 6	93.01 %	96.95 %	25.80 %	17.08 %	16.46 %	8.89 %
AT 7	85.75 %	91.67 %	34.87 %	27.46 %	27.53 %	20.00 %
AT 8	80.07 %	89.38 %	38.46 %	30.09 %	41.14 %	27.78 %
AT 9	61.63 %	78.76 %	46.67 %	40.11 %	66.46 %	50.00 %
AT 10	46.5 %	60.42 %	42.26 %	44.50 %	55.38 %	65.56 %
Alg 1	76.63 %	86.66 %	36.89 %	30.88 %	36.89 %	29.76 %
Alg 2	54.23 %	79.34 %	46.56 %	38.44 %	46.56 %	46.46 %
Alg 3	65.93 %	86.07 %	42.96 %	32.33 %	42.96 %	36.38 %
Alg 4	56.16 %	77.81 %	46.25 %	40.53 %	46.25 %	47.76 %
Alg 5	41.73 %	55.66 %	38.63 %	41.17 %	38.63 %	50.75 %
Alg 6	86.97 %	96.73 %	32.54 %	18.28 %	32.54 %	12.69 %
Alg 7	50.97 %	72.7 %	40.71 %	40.41 %	40.71 %	61.01 %
Alg 8	9.86 %	17.09 %	25.31 %	34.06 %	25.31 %	25.56 %
Alg 9	31.34 %	42.24 %	25.20 %	29.38 %	25.20 %	32.21 %
Alg 10	45.69 %	62.76 %	42.44 %	45.14 %	42.44 %	62.69 %
FC 1	61.02 %	82.77 %	47.71 %	36.98 %	57.14 %	41.23 %
FC 2	72.49 %	88.7 %	43.61 %	31.42 %	47.40 %	26.12 %
FC 3	30.2 %	50.28 %	33.19 %	42.60 %	38.15 %	55.22 %
FC 4	36.74 %	46.42 %	38.08 %	41.89 %	37.99 %	45.52 %
FC 5	55.91 %	52.1 %	47.24 %	47.84 %	39.61 %	47.95 %
FC 6	78.85 %	88.65 %	36.39 %	28.51 %	31.82 %	23.88 %
FC 7	68.82 %	90.13 %	42.61 %	28.98 %	73.05 %	27.80 %
FC 8	75.36 %	91.1 %	39.66 %	26.82 %	55.84 %	22.01 %
FC 9	18.55 %	24.03 %	28.79 %	35.19 %	16.23 %	35.26 %
FC 10	34.95 %	54.35 %	40.59 %	45.70 %	47.08 %	59.33 %

Figure 7.2: 2020 MathsFit quiz results and discrimination indexes.

Quizzes were delivered in 2021 using the open-source e-assessment tool Numbas (https://www.numbas.org.uk/) through Brightspace. Numbas features include a randomisation of question and possible answer variables. Hence, students do not see the same quiz as their peers or the same quiz if a second attempt is necessary, an improvement on the static quiz format of Brightspace. The use of Numbas, designed to assess mathematics, meant that mathematical notation was much easier to display in the quiz. Unfortunately, many students completing their first attempt in-person during tutorials in 2021 experienced technical issues with Numbas, creating a stressful experience. Students who missed a question in the quiz were difficult to identify as a zero score for a question could mean a missed question or a wrong answer. The dataset was too large to identify these missing answers through the answer records for all students. However, the vast majority of technical issues were experienced during students' first quiz attempt in a tutorial. When this occurred the researcher or tutor present noted which quiz parts they could complete. Their mark for a section was then based on the parts they completed. As most students with technical issues attempted the quiz a second time, therefore completing the missing parts, an accurate measurement of their ability to answer all the quiz questions was collected eventually.

In 2022, the MathsFit quiz and Refresher Course were hosted in Bolster Academy, a commercial platform that offered more technical support than Numbas' admirable community-led platform. It was hoped students would experience less technical issues using Bolster Academy, and if they did, there would be more trained staff to assist with a timely solution. The quiz questions were re-formatted and transferred to the Bolster Academy system by their support team. The quiz time restriction was removed, meaning students could take as long as they wished to complete the quiz.

7.4.3 Feedback emails

Utilising Intelligent Agents and Release Conditions features of Brightspace each student was sent a personalised email within 24 hours of their first attempt at the MathsFit quiz. It included their results for each of the three sections and a set of feedback instructions detailing advised support and how they might make a second quiz attempt, if necessary. The email wording was pre-programmed and dependent on their quiz score which had four bands of classification. The classifications were built on the three categories, called "medals" from 2021 onwards, that were determined by a quiz section's marks. In 2020, Gold or High represented greater than or equal to 90%, Silver or Medium between 70% and 89.99%, and Bronze or Low for less than 70%. These categories had high thresholds as the aim was mastery (Campbell et al., 2020). Each student received a classification of three letters corresponding to a feedback email. For example, a student who scored GSB (or HML), denoting Gold-Silver-Bronze (or High-Medium-Low), meaning they achieved 90% or more in Arithmetic and Trigonometry, between 70% and 89.99% in Algebra, and less than 70% in Functions and Calculus, received an email advising that they were proficient in Arithmetic and Trigonometry, should briefly revise Algebra in the Refresher Course, and should revise Functions and Calculus using the Refresher Course and a MSC visit. Students who scored all Gold or HHH, the highest classification possible, were invited to lead a study group of their peers under the facilitation of a senior MSC tutor. The study groups were advertised to students who scored two or more Bronzes (or Lows). Example emails from each of the four classifications are available in Appendix K.

Students who did not score in the highest band were invited to retake the MathsFit quiz the week after their first attempt in order to gain additional academic credit, in module B students' case, or refresh their mathematics, in module A's case. This allowed for measurement of students' improvement and further identification of students who still scored poorly after being offered initial support. Another personalised feedback email, based on the same classification system was sent once students completed their second attempt. This email was based on their combined classification, using the best of both their attempts. It notified them of their updated continuous assessment percentage, where relevant, and encouraged them to continue to use the MSC, as necessary, through the rest of their first year.

The design of the feedback emails remained broadly consistent throughout 2020, 2021, and 2022. Based on student feedback from surveys and interviews in 2020, the language of the feedback emails was updated to be more encouraging (promoting a growth mindset) to students and the medal terminology, Gold, Silver, and Bronze, was used instead of High, Medium, and Low. In 2021, as each quiz section had eight questions instead of ten, the percentage thresholds for the medals changed slightly. Gold was achieved by earning greater than 90%, Silver for between 75% and 89.99% inclusive, and Bronze for less than 75%. This was based on less than one incorrect question (partial marks were available for some questions), one or two incorrect questions, and three or more questions wrong, respectively. In 2022, this was changed to Gold being greater than or equal to 87.5%, Silver being greater than or equal to 62.5% and less than 87.5%, and Bronze being less than 62.5%. This was a return to assigning medals based on the same number of answers that were incorrect as in 2020. That is, each of the eight questions in a quiz section was worth 12.5% of that section so Gold was set at one incorrect question or less, Silver: two or three incorrect questions, and Bronze: four or more incorrect questions. The 2021 medal thresholds, on reflection, were set too high. The support measures suggested for each medal award remained the same in 2020, 2021 and 2022.

7.4.4 Refresher Course

The Refresher Course in 2020 was hosted in Moodle and contained videos and worksheets previously made by MSC staff, organised by quiz section and question. Students, knowing which quiz questions they struggled with, could view an appropriate video that explained the theory and showed examples of similar questions for the topic assessed. Students were given instructions on how to access the appropriate Moodle page in their feedback email and so could not access it before receiving their feedback email. The Moodle courses contained 16 pages of content with each page having one or more videos. Three of the pages related to Arithmetic and Trigonometry content, eight to Algebra content, and five to Functions and Calculus content.

In 2021, to provide students with a chance to prepare for the quiz if they wished, students had the option to engage in the Refresher Course (RC) before (and after, if necessary) attempting the quiz in their first tutorial. This necessitated hosting the Refresher Course in the module's Brightspace site with the quiz and surveys. Interactive practice questions were also added to the RC with a number of similar questions per quiz question available. To match the style of the quiz and for advantages such as corrective feedback and multiple attempts at questions, the RC practice questions were also hosted in Numbas through Brightspace. Western Sydney University Numbas resources and freely available Numbas questions were analysed and adapted as practice questions for the RC. The videos from 2020 were available in the same Brightspace section as the links to the questions in Numbas. The RC had slightly different content for each module to align with the differing quiz content and differing mathematical levels of the students.

The RC in 2022 was hosted between Brightspace and Bolster Academy with the MSC videos in Brightspace and a selection of carefully curated interactive practice questions in Bolster Academy. The practice questions were chosen from Bolster Academy's pre-existing set of Basic Math package questions to align with the quiz questions, module content, and prior learning. However, some topics (e.g., differentiation for modules A, B, and C) did not have questions but an informative interactive page.

7.4.5 Surveys

Initially, two surveys were designed to gather information about MathsFit participants and their experience of MathsFit. The first survey, completed before students started the quiz, asked for their consent (the information letter is in Appendix L) to participate in the research project MathsFit, their gender, whether they were international or domestic students, their degree choice, which mathematics examination they had taken previously (e.g., Leaving Certificate, A-Level, Quality and Qualifications Ireland (QQI)), the grade they obtained in that examination, satisfaction with their mathematics result and their overall results from their previous set of examinations, and what grade they had expected to receive in their previous mathematics examination. Students were also asked whether they had covered their mathematics curriculum, with listed mathematics topics to select if they had not covered them, and some questions on mathematical anxiety. All pre-survey questions were either multiple choice (with an "Other" fill in the box option), Likert scales or fill-in the box. The pre-survey is available in Appendix M. Students answered the second survey after they completed the quiz. It asked if they had enough time in each quiz section, whether they felt anxious during the quiz, and if they had any other comments. The post-survey is available in Appendix N. Both the pre-and post-survey were hosted in Brightspace and were linked to the quiz sections, so students were led from the pre-survey through the three quiz sections and on to the post-survey.

When the redesign for MathsFit 2021 was commencing in May 2021, it was identified that a further survey, gathering information about students' MathsFit experience and recruiting students for interviews, would be beneficial. The follow-up survey (in Appendix O), hosted in Google Forms, asked students different questions based on their number of quiz attempts (once, twice, or not at all). All students were asked how clear MathsFit communication (emails, video, feedback) was on a scale from one (not at all clear) to five (as clear as possible), what types of mathematics support they had used (e.g., MSC, online resources, peers) if any, to suggest ways to improve MathsFit, for further explanation of their answers or any other feedback, and if they were willing to be interviewed about their experience of MathsFit. Non-quiz takers were additionally asked for reasons why they did not participate, and if they were aware of the MSC and if so, had used it. Those who attempted the quiz once were asked how difficult they found the quiz on a five-point scale of "very easy" to "very difficult", how they felt about their quiz result on a five-point scale of "very disappointed" to "very happy", and why they attempted the quiz once only. Those who completed two attempts were also asked about the quiz difficulty and how they felt about their first and second attempt quiz results using the same scales. They were asked if the set time interval between attempts was too long, too short, or just right and for an explanation of their response. Students who completed one or two attempts were then asked what support from the feedback email they used and answered different questions based on which answer they selected. Those who had used the support were asked about the helpfulness of the support on a five-point Likert scale from "not at all helpful" to "very helpful" with a follow-up question asking for an explanation for their rating. Those who did not use the support were asked why they had not, and whether they were aware of and had used the MSC. Those who could not remember or did not receive a feedback email were asked if they were aware of and had used the MSC. The relevant results of this survey and the others will be presented in Section 7.6.1 Student Feedback.

The pre-survey questions remained the same in 2021 with a reduction in the number of questions on mathematics anxiety, and slight changes to clarify language. Further research into mathematics anxiety revealed that it is not good practice to measure students' mathematical anxiety just before an assessment (Gokhool, 2023). Question language was edited to make the questions less Leaving Certificate centric and more applicable to international students. The degree question options were updated to include those applicable to the Science and Engineering cohorts. The post-survey additionally asked if students generally felt confident about their answers, unsure about their answers, or did not know the answers, in each quiz section. The 2021 version of the post-survey is available in Appendix N.

The 2021 follow-up survey ran six weeks after access to the MathsFit quiz ended so students would remember MathsFit but also have had more experience of university mathematics. The style of the follow-up survey, hosted in Google Forms, where students were asked different questions based on how many times they attempted the quiz, remained the same, and questions were broadly similar to the 2020 follow-up survey. Additional questions were: if students had studied for the Leaving Certificate examination in 2021 did they chose to take the examination or opt for calculated grades[10], if they experienced technical difficulties during the quiz, if they preferred to complete the quiz in a tutorial or outside of it, if they engaged with the Refresher Course before their first quiz attempt, and if they would have liked more structured revision time before their first quiz attempt. The 2021 follow-up survey is available in Appendix O.

Four surveys took place in 2022: the established pre-survey and post-survey completed directly before and after students' first quiz attempt, a new post-second attempt survey completed directly after students' second attempt at the quiz, and the follow-up survey sent six weeks after the MathsFit quiz closed. The pre- and post-quiz (attempt one) surveys remained the same but the post-survey did not include time-related questions as there was no longer a quiz time limit. A post-second attempt survey was introduced to gather greater student feedback as the follow-up survey from 2021 had a low response rate (15.12%), perhaps due to being advertised via email. The post-second attempt survey was hosted in Brightspace, like the pre- and post-surveys, therefore a greater response rate was expected. The post-second attempt survey asked students to rate the difficulty of the quiz, their reaction to their first attempt results, and MathsFit communication. The survey also asked if students had engaged with the Refresher Course and to rate its helpfulness. Students' awareness of the MSC was sought, and whether they had further feedback. The follow-up survey was still sent to students via email six weeks after they participated in MathsFit. It was shortened to encourage more students to complete it. The 2022 surveys appear in Appendices M, N and O.

7.5 Participants

Over the three iterations of MathsFit reported on in this paper, 3,268 students consented to participate in the research. Table 7.2 presents the number of MathsFit participants and their demographic information by module and year. Students were asked in the pre-survey for their gender (Male, Female, Non-binary, or Prefer not to say), whether they were international or domestic students, and what type of examinations they had taken previously (e.g., Leaving Certificate, A-levels). Table 7.3 presents the previous education systems other than the Leaving Certificate.

[10] In 2021 students could choose to have calculated grades (as the 2020 cohort had) or sit their examinations as before (pre-2020) or both, which took the best results of both. The 2021 examinations had additional choice to reflect the lost in-person school time due to COVID-19. https://www.citizensinformation.ie/en/education/state-examinations/leaving-cert-accredited-grades/

Table 7.2: Demographics of MathsFit participants.

Module & Year	Participants	Female, Male	International	Leaving Certificate
A 2020	253	59.29%, 40.32%	1.98%	94.07%
B 2020	449	48.11%, 51.67%	7.80%	88.64%
A 2021	335	61.79%, 37.31%	3.58%	87.76%
B 2021	458	47.16%, 52.18%	7.86%	87.34%
C 2021	258	64.73%, 34.88%	9.30%	84.50%
D 2021	316	28.16%, 70.89%	8.23%	91.77%
E 2021	68	44.12%, 54.41%	100%	0.00%
A 2022	179	63.13%, 35.75%	3.35%	92.74%
B 2022	413	52.30%, 47.46%	11.13%	86.44%
C 2022	263	66.92%, 29.28%	11.41%	78.33%
D 2022	234	28.63%, 70.51%	5.98%	94.02%
E 2022	42	59.52%, 33.33%	100%	0.00%
Total	3,268	51.16%, 47.89%	10.53%	85.28%

Table 7.3: MathsFit participants' pre-university education.

Module & Year	A-level	GCSEs	International Baccalaureate	MSAP [11]	QQI	SATs[12]	UCD Access	Other
A 2020	0.00%	0.00%	0.40%	0.00%	3.95%	0.00%	0.00%	1.58%
B 2020	0.45%	0.45%	0.89%	0.00%	3.79%	0.00%	0.00%	5.79%
A 2021	0.30%	0.00%	0.60%	1.19%	7.46%	0.60%	0.30%	1.79%
B 2021	1.09%	0.44%	0.87%	0.00%	4.59%	1.53%	0.00%	4.15%
C 2021	0.78%	0.00%	1.94%	0.00%	5.43%	1.55%	1.93%	3.88%
D 2021	0.95%	0.32%	0.32%	0.00%	0.00%	0.95%	2.22%	3.48%
E 2021	0.00%	0.00%	7.35%	0.00%	0.00%	55.88%	0.00%	36.76%
A 2022	0.56%	0.00%	0.00%	1.12%	3.35%	0.00%	0.00%	2.23%
B 2022	1.69%	0.24%	0.97%	0.00%	3.63%	1.45%	0.73%	4.84%
C 2022	1.52%	0.76%	2.28%	0.38%	7.98%	1.90%	1.52%	5.32%
D 2022	0.85%	0.00%	0.85%	0.00%	0.00%	0.00%	0.43%	3.85%
E 2022	0.00%	0.00%	14.29%	0.00%	0.00%	52.38%	0.00%	33.33%
Total	0.83%	0.24%	1.22%	0.21%	3.95%	2.66%	0.64%	4.96%

Figure 7.3 shows students' mathematical achievement based on their most recent mathematics examination converted to a scale of 1-9. A score of 9 is equivalent to a Leaving

[11] Mature Students Admissions Pathway
[12] Scholastic Aptitude Test (USA education system)

Certificate H1 (90%-100%, the highest grade achievable) or an A-levels A* or a "7" in the International Baccalaureate, 8 is equivalent to a Leaving Certificate H2, and so forth. Conversions to the nine point scale were based on UCD entry requirements (University College Dublin, 2021) for all examination systems mentioned by students. The conversion table is available in Appendix Q. Note, for ease of presentation the years in the horizontal axis of Figure 7.3 are shortened, for example, A 21 denotes module A in the year 2021. As presented in Table 7.1, the modules had different entry requirements and this is reflected in the spread over 1-9 for each module. For the majority of students[13] module A requires at least "1", modules B and C require at least a "4", and module D requires at least a "6" in Leaving Certificate mathematics. Students in module E are expected to have a similar standard as module D.

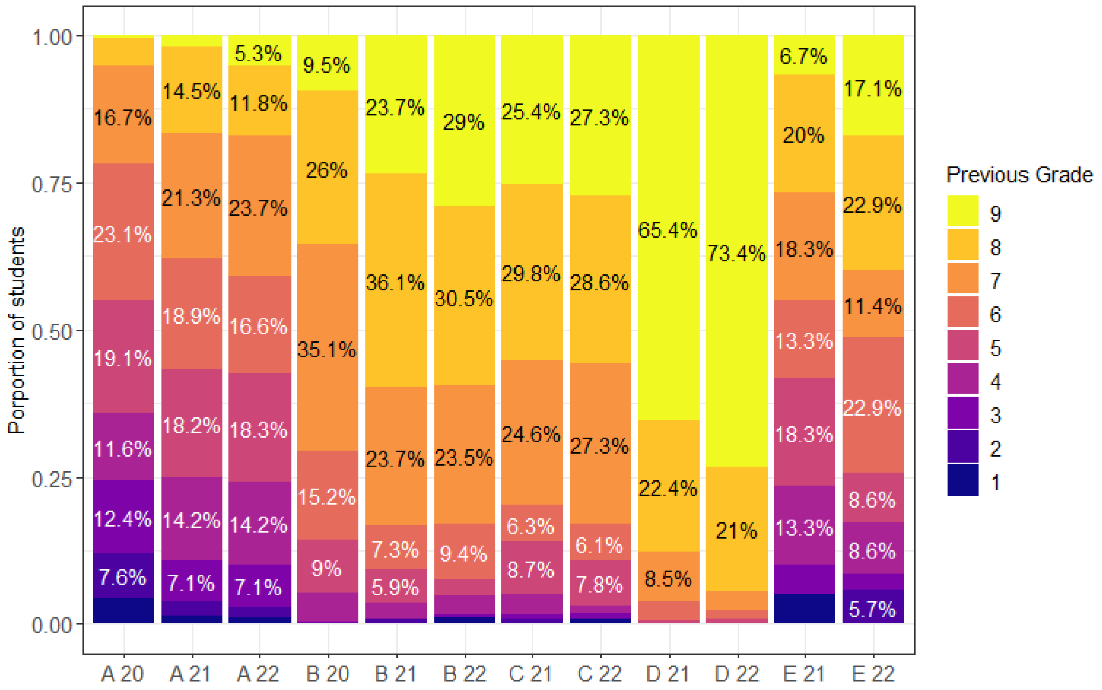

Figure 7.3: MathsFit participants' converted previous mathematics grades.

As outlined in Section 7.4 Design, there were a number of different elements to MathsFit. Table 7.4 outlines how many students per year participated in each element. Participation per element was similar across modules, with the exception of module A which had notably lower participation rates in Quiz Attempt 2, most likely due to students prioritising credit-bearing work. In Table 7.4 an asterisk indicates that the number of students who started the quiz and submitted the quiz is different. In 2021, 106 students did not submit the quiz and in 2022, 41 did not submit the quiz. Every effort was made to allow late-registered students (those who missed the initial emails advertising MathsFit and, for some, the timetabled quiz attempts) to participate in MathsFit by giving these students additional days to complete their quiz attempts and engage with the Refresher Course, but some late registrations were too late (registering to the module after the extended

[13] Schemes such as HEAR and DARE allow students entry to a course with lower entry requirements.

MathsFit deadline) and therefore are missing from the dataset. There were less than 20 students who registered after MathsFit advertising emails per module per year and most of them participated in MathsFit.

Table 7.4: MathsFit participants' engagement with its various elements.

Year	2020	2021	2022	Total
Pre-survey	702	1,435	1,131	3,268
(% of total registrations)	(81.25%)	(86.55%)	(67.97%)	(78.07%)
Quiz Attempt 1	702	1,417*	1,052*	3,171
Post-survey	656	1,176	1,053	2,885
Quiz Attempt 2	343	678	485	1,506
Post-Attempt 2 survey	0	0	245	245
Follow-up survey	39	216	287	542
Interviews	1	3	5	9
Refresher Course use	189	955[14]	1,043	2,235
MSC visits	183	179	175	537
Study group participants	16	3	1	20

Survey responses and interview data, as the source of student feedback that impacted the design of MathsFit, were examined for representativeness in terms of module, gender, international status, previous education systems[15], previous mathematical results, MathsFit Quiz results, and final mathematics module results. Survey responses were tested with chi-squared (χ^2) tests and t tests to compare survey respondents to all MathsFit participants. The representativeness of the 2020 follow-up survey was unable to be examined as it was anonymous and did not ask any demographic questions. This was corrected in the 2021 and 2022 follow-up surveys where student numbers (unique identifier for each student) were requested. Some students who did not consent for their demographic, previous education and assessment results to be used completed a follow-up survey. These students (17 from 2021 and 49 from 2022) did consent for their follow-up survey responses to be included but will not be included in the following analysis of representativeness as their demographic and assessment data is unknown. Response rates presented in the analysis were calculated only with participants who consented via the pre-survey.

Post-survey respondents (88.28% of participants) were representative of the MathsFit sample in terms of gender ($\chi^2(3)=0.55$, $p>.05$), international status ($\chi^2(1)=2.54$, $p>.05$), previous examination system ($\chi^2(8)=3.27$, $p>.05$), and previous mathematics results ($\chi^2(8)=6.0287$, $p>.05$). However, they

[14] Due to some missing data, this number may be a slight underestimation. This is irrelevant to this paper's results.

[15] This category was binary, Leaving Certificate or not, for the follow-up surveys and Attempt 2 post-survey to meet chi-squared test assumptions as most other examination systems had low frequency.

had statistically significantly higher MathsFit quiz results ($t(5575)=-3.68$, $p<.001$) and mathematics module results ($t(5634)=-4.56$, $p<.001$). Post-survey respondents were not representative of each module as there were significantly less module A respondents in 2022 (($\chi^2(11)=81.25$, $p<.001$). The 2021 follow-up survey respondents (13.87% of 2021 participants) were representative of the 2021 MathsFit participants in terms of module ($\chi^2(4)=6.12$, $p>.05$), gender ($\chi^2(3)=4.97$, $p>.05$), international status ($\chi^2(1)=0.18$, $p>.05$), previous examination system ($\chi^2(1)=0.20$, $p>.05$), and previous mathematics grade ($\chi^2(8)=6.21$, $p>.05$). However, the 2021 follow-up survey respondents had higher MathsFit results ($t(256)=4.60$, $p<.001$) and final module results ($t(280)=3.0217$, $p=.003$). The Attempt 2 post-survey and 2022 follow-up survey had 21.66% and 21.04% response rates respectively, with 73 students (6.45%) answering both surveys. Both surveys' respondents had significantly higher MathsFit results ($t(493)=4.65$, $p<.001$; $t(383)=3.83$, $p<.001$) and final mathematics module results ($t(404)=6.69$, $p<.001$; $t(345)=4.07$, $p<.001$), and were not representative in terms of students' modules ($\chi^2(4)=16.91$, $p<.001$; $\chi^2(4)=25.87$, $p<.001$) or previous grade ($\chi^2(8)=18.79$, $p<.025$; $\chi^2(8)=19.89$, $p<.025$). Modules C, D, and E were overrepresented in the follow-up survey with modules A and B underrepresented, while module A was underrepresented in the Attempt 2 post-survey, with the other modules overrepresented. More students with higher previous grades were than lower grades answered both surveys causing an overrepresentation of higher previous grades. The follow-up survey in 2022 was also not representative of previous examination systems ($\chi^2(2)=48.00$, $p<.001$) with Leaving Certificate students underrepresented compared to the 2022 MathsFit sample. Domestic students were also significantly underrepresented ($\chi^2(1)=11.28$, $p<.001$). However, the 2022 follow-up survey was representative of gender ($\chi^2(3)=3.61$, $p>.05$). The Attempt 2 post-survey was representative of gender ($\chi^2(3)=1.97$, $p>.05$), international status ($\chi^2(1)=0.64$, $p>.05$), and previous examination system ($\chi^2(2)=0.22$, $p>.05$) in comparison to the 2022 MathsFit sample.

Due to the small number of interviews, the assumptions of the chi-squared test and t test were not met and so the representativeness of interviewees will be compared narratively. There were two interviewees from each of module A, B, and C, and three from module D. There were seven male interviewees and two female, and all except one were domestic students. Most interviewees had high previous mathematics grades, MathsFit quiz results and module results, so lower achievers were not as well represented among the interviewees. Only two interviewees had a previous mathematical grade that was equivalent to a H4 or lower. All except one interviewee scored above 80% overall in the MathsFit quiz, with all achieving Gold in the Arithmetic and Trigonometry section. One interviewee failed their mathematics module, but six scored in the A range (70%-100%). A range of previous education systems were represented. Two interviewees completed International Baccalaureate examinations, one completed A-level examinations, one completed the UCD Access course, and the others completed the Leaving Certificate.

7.6 Results

7.6.1 Student feedback

The various MathsFit redesigns incorporated student feedback where practical. There were two sources of open student feedback, namely open responses from the post-quiz survey's final question "Any comments about MathsFit?" which was answered by 56% of total participants across the three years, and the nine in-depth interviews conducted with MathsFit participants. One online interview was conducted in July 2021, three online interviews in November 2021, and five in-person interviews in November 2022. Semi-structured interviews lasted on average 25 minutes and were driven by the research question "What is the student experience of MathsFit?". Analysis of interviews and open survey question responses was guided by Braun and Clarke's (2006) reflexive thematic analysis approach, where themes around communities were identified. More quantitative results, from the post-surveys, post-Attempt 2 survey, and the follow-up surveys will be presented alongside the qualitative analysis to highlight more students' views of MathsFit.

Student interview quotes in this section are represented by a letter and two digits corresponding to their modules' assigned letter—A, B, C, D, or E, and the year in which they completed MathsFit, 2020, 2021, or 2022. For example, B22 represents an interviewee who took Module B in 2022. Quotes from survey responses will be indicated with S as the first letter to indicate survey responses, then a second letter A, B, C, D, or E indicating their module. For example, SB20 denotes a Business student's survey response from the academic year 2020/21.

7.6.1.1 Different student groups' impressions of MathsFit

The majority (85.28%) of MathsFit participants had just completed the Leaving Certificate (LC), in the June of their year of participation. In March 2020, secondary schools moved exclusively to online learning and LC examinations did not occur. Many LC students' reactions to MathsFit were similar to the survey response comment of SB20: "This is the first time I've done maths since March." MathsFit was an important revision tool for these students who had not engaged with mathematics for several months. This response trend continued in subsequent years even when formal LC examinations had resumed. These 2021 and 2022 LC students also revealed surprise at their loss of mathematics proficiency over the summer months.

A significant minority (10.53%) of MathsFit participants are international and thus completed their secondary education outside the Republic of Ireland. For them MathsFit offers an opportunity to compare curricula and find out what they are expected to know for success in their university mathematics module. This was highlighted in an interview with an international student (C21) who found the MathsFit Refresher Course "very positive" in demonstrating the required knowledge.

This feature of communicating mathematical expectations was also discussed by a module B student in 2022 who did not proceed from secondary education to tertiary education immediately: "I took two years off before coming back to school [university] so it was nice to get a presentation of … the stuff that you will have to [do] or you're expected to know… a soft landing."

A mature student (C22) who completed UCD's year-long Access programme before entering first-year Science also discussed the loss of mathematical proficiency over the summer months, similar to LC students, but this was compounded by their longer break from mathematics before that course. These students highlight how MathsFit was useful to them, with communication of mathematical expectations at university, and revising basic mathematics following a break in their studies.

7.6.1.2 Timing of MathsFit

The timing of MathsFit was not ideal and numerous students remarked on this. A frequent refrain in the post-survey particularly in 2020 and 2021 was similar to SB20's: "Should give students at least a week to settle in before a quiz like this as it stressed a lot of people out." This was explored further in interviews and a module C student explained it was "a bit scary" and "overwhelming" at the beginning not understanding what had to be done, but they "didn't mind that much overall in the end". Students new to university can understandably be overwhelmed as MathsFit is their first interaction with university assessment and it comes so early in their university experience. To counteract this the first tutorial which introduced MathsFit in 2022 explicitly addressed these concerns and this type of feedback was less common in 2022. The 2021 follow-up survey found that a slight majority (53-68%) of students in every module but module A (44%) preferred to complete both quiz attempts outside of tutorial time. A majority (63-81%) in each module wanted more structured revision time before their first attempt at the quiz. Hence, with only one tutorial available to be used for MathsFit, the focus of the tutorial became MathsFit as a whole, instead of merely the MathsFit quiz.

Mature students who had completed UCD's Access programme found themselves at an advantage in that they were already somewhat familiar with the university. However, the timing still did not suit perfectly. A22 actively engaged with MathsFit, spending a lot of time in the MSC, but then was spending too much time relative to their other work and had to "drop it". They desired earlier access to MathsFit prior to the beginning of lectures so they could spend more time on it.

MathsFit occurring in students' first two weeks of classes means other responsibilities overlap with their participation. If students discover, through MathsFit, that they require a lot of support in reaching an appropriate level of mathematics proficiency, this can lead to a workload conflict. Another challenge is MathsFit running alongside the teaching of new mathematical content within the modules it is part of. Student D22 discussed how having a focus on just MathsFit for the first week of classes would be beneficial instead of learning new content in lectures and revising mathematics in the first tutorial and outside of classes as that was “a bit confusing”.

When asked for their opinion on whether MathsFit could take place earlier, for example, in the students’ orientation week, the response was varied. Student A22, a mature student who had the benefit of being familiar with UCD including the VLE, felt confident other students would be able to navigate the system without much guidance, describing their younger peers as “tech savvy”. However, feedback from these younger students suggested otherwise as SB22 explained they found it difficult to adjust to Brightspace in the beginning. Many MathsFit participants cannot be expected to participate without explicit instruction in how the technology works. Instruction in using UCD technology, the VLE and other applications like Google Drive, can be part of students’ orientation week. However, the timing of these was less exact during 2020-2022 due to first-year students starting two weeks later than normal. Also, even with instruction, students take time to adjust to the new technology, time they may not have before engaging with MathsFit. The 2022 tutorials attempted to solve this issue by creating an opportunity for students to get used to the MathsFit part of Brightspace and Bolster Academy by having them access the Refresher Course in the tutorial, under the supervision of tutors, but based on SB22’s comment, among others, the issue of not enough time to adapt remained.

7.6.1.3 Awareness and use of the MSC

A key aim of MathsFit is to raise student awareness of the MSC. Unfortunately, little qualitative data on MathsFit participants’ use of the MSC was obtained as only two of the nine interviewees had used it, the others discussing how they were aware of it but had not yet needed to use it. Both students who had used it were mature students and felt it was a great resource though they had issues with noisy environments and high volume of students relative to the number of tutors. Nevertheless, A22 really appreciated the MSC tutors highlighting their non-judgmental qualities and calling them “a lifeline”.

Follow-up surveys asked students, who indicated they had not used the follow-up supports advised in the feedback email or attempted the quiz, if they were aware of the MSC. In 2021, only 5.5%, seven students, replied in the negative. Over 83% were aware of the MSC and had not used it, while the remaining 11% had used the MSC. The post-Attempt 2 survey also asked students if they were aware of the MSC, and 241 of the 245 students who answered the survey, that is, 98.37% said “yes”.

7.6.2 Quiz results

As presented in Table 7.4 earlier, over the three iterations, 3,268 students participated in MathsFit with 3,155 (96.54%) having complete quiz results. Some 21 students completed two sections instead of three, 17 completed only one section and 75 did not complete any quiz section but gave consent via the pre-survey for their other data to be used. There were 76 students who did not complete the Arithmetic and Trigonometry (AT) section, 94 who did not complete the Algebra (Alg) section and 110 who did not complete the Functions and Calculus (FC) section in Attempt 1 or Attempt 2.

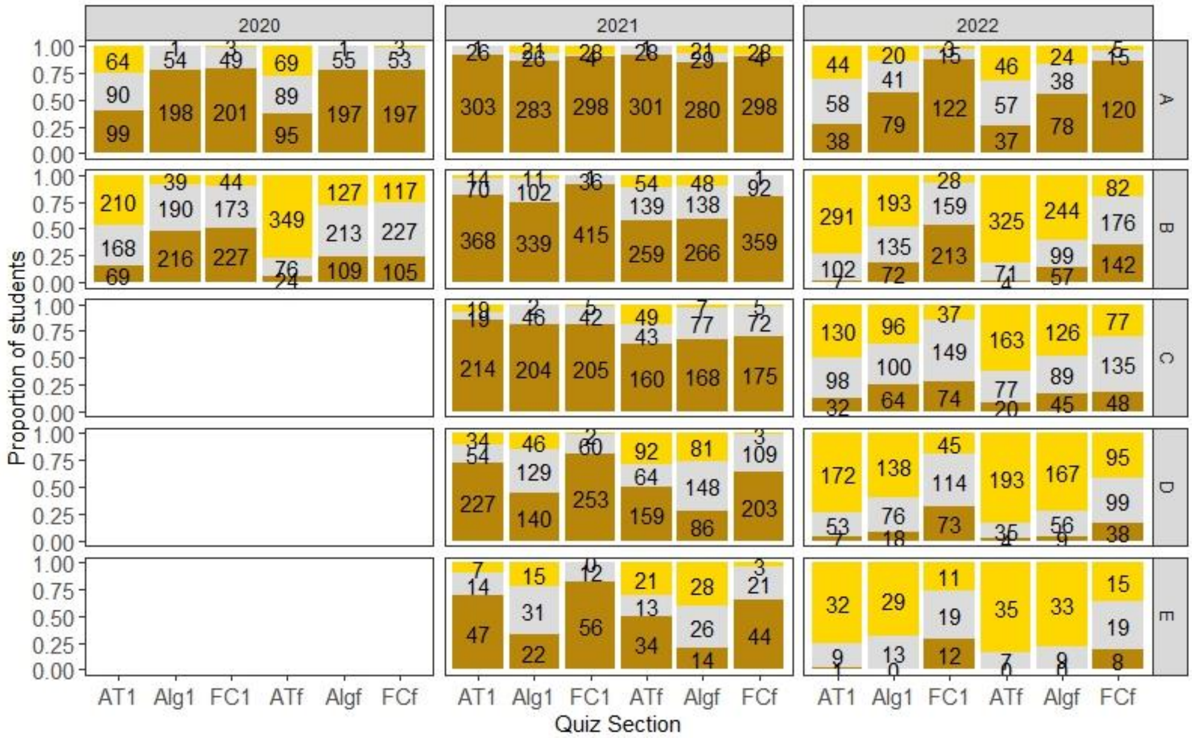

Figure 7.4: MathsFit participants' quiz medals for their first attempt and final result by quiz section, year and module.

Figure 7.4 shows the medals achieved by the participants in each quiz section. Their first attempt (AT1, Alg1, and FC1) and their final medal classification (ATf, Algf, and FCf) are presented by module and year. The final medal classification is based on the best of both attempts by section. For example, a final medal classification of GSS could be Gold in AT in the first attempt, Silver in Algebra in the second attempt (after a Bronze in the first attempt), and Silver in FC in their first attempt (after achieving Bronze in their second attempt). Table 7.5 presents the percentage boundaries of each medal for each year, with x representing a student's percentage result for a quiz section.

Table 7.5: MathsFit quiz medal boundaries.

Year	Gold	Silver	Bronze
2020	$x \geq 90\%$	$70\% \leq x < 90\%$	$x < 70\%$
2021	$x \geq 90\%$	$75\% \leq x < 90\%$	$x < 75\%$
2022	$x \geq 87.5\%$	$62.5\% \leq x < 87.5\%$	$x < 62.5\%$

7.6.2.1 Quiz results compared by section

Figures 7.5, 7.6, and 7.7 are boxplots of students' percentage results in each quiz section. This is their final quiz section result, either their Attempt 1 quiz section percentage or Attempt 2 quiz section percentage, whichever was better. All three quiz section results in aggregate did not meet the assumptions of the ANOVA and Tukey HSD tests. Instead, Kruskal-Wallis and Dunn tests were used to determine differences between years of the same module and between modules in the same year. For example, differences between A 2021 and A 2022, and A 2021 and B 2021 are shown if significant while the difference between A 2021 and B 2022 is not shown even if significant, as this was not of interest in the current analysis. The asterisks indicate the level of significance, where three asterisks indicates $p<.001$, two indicates $p<.01$, and one $p<.05$. Effect sizes for these differences were calculated using ε^2 (King et al., 2018).

AT, or Arithmetic and Trigonometry, quiz section results had statistically significant differences between the results of the modules with relatively large effect size ($H(11)=1129.18$, $p<.001$, $\varepsilon^2=0.35$, CI= 0.32, 0.37). The differences indicated by this result were found by the Dunn test and are shown in Figure 7.5. The differences between years of the same module are shown above the horizontal axis revealing differences between each 2021 module and its 2022 counterpart and between 2020 modules and their 2021 counterparts, but not between the 2020 modules and the corresponding 2022 modules.

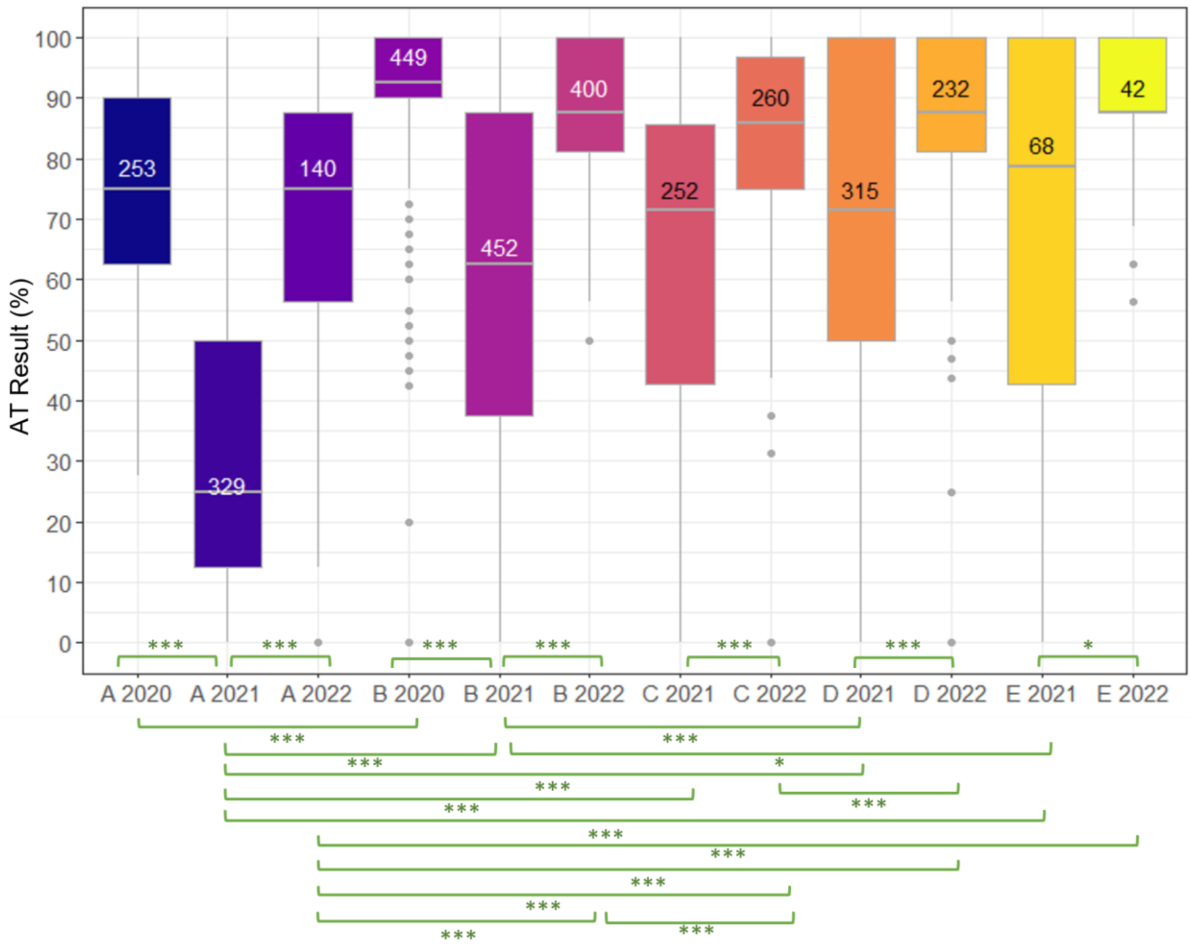

Figure 7.5: Arithmetic and Trigonometry quiz section results with differences between cohorts identified.

All shown differences in Figure 7.5 have p<.001 except the difference between E 2021 and E 2022. Below the horizontal axis the differences between modules in the same year are shown including differences between each A and B module in all three years, and differences between module A and modules C, D and E in both 2021 and 2022. Module B is also different to modules D and E in 2021. Modules D and E are more similar in their AT results with no significant differences between them in either 2021 or 2022. This is somewhat expected as both cohorts were studying Calculus for Engineers and were expected to have a similar prior mathematical knowledge.

Similarly, the Algebra quiz sections had significant differences between the module groups ($H(11)=912.08$, $p<.001$, $\varepsilon^2=0.28$, CI=0.26, 0.31) and the differences found by the Dunn test are shown in Figure 7.6. The differences between years of the same module, shown above the horizontal axis, reveal significant differences only between the A modules and B modules except 2020 and 2022 and between C 2021 and 2022. This means that the results of the two D modules and E modules were similar and A 2020 and A 2022, and B 2020 and B 2022 had similar algebra results too.

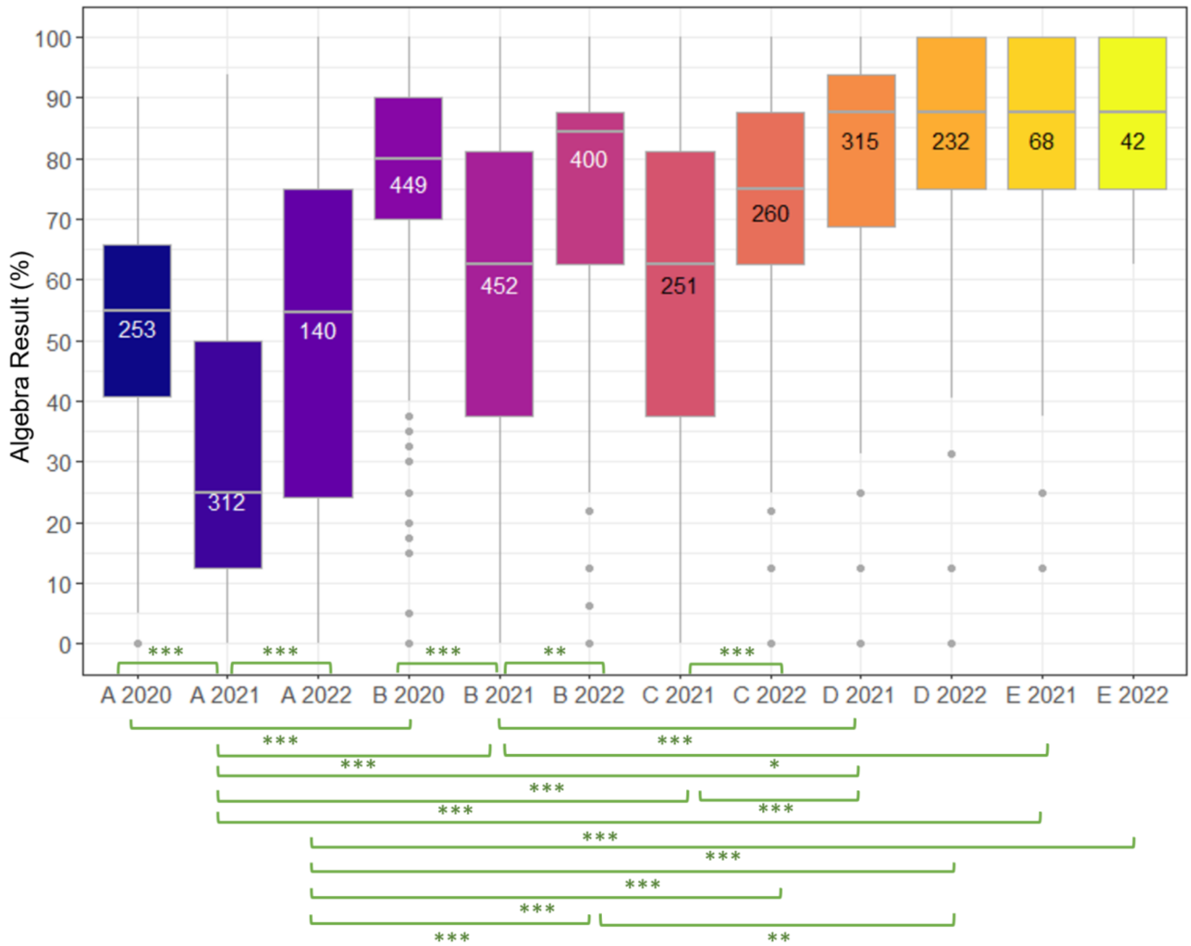

Figure 7.6: Algebra quiz section results with differences between cohorts identified.

Looking at differences between modules in the same year in Figure 7.6 there were again significant differences between modules A and B in each year, and between module A and all of the other modules in 2021 and 2022. Module B was again different to modules D and E in 2021. In contrast to the AT quiz results, the Algebra quiz results also had significant differences between B 2022 and D 2022, between module C and modules D and E in 2021, and between modules C and E in 2022. This was due to module C's lower results in Algebra while modules D and E's results remained high while in AT all three modules had high average results. Similarities between modules D and E in both years remain.

The FC, or Functions and Calculus, quiz section also had significant differences between the modules ($H(11)=969.88$, $p<.001$, $\varepsilon^2=0.30$, CI=0.28,0.33), shown in Figure 7.7. Above the horizontal axis, differences between A 2020 and A 2021, and A 2020 and A 2022; between each of the B modules; and between the two C modules are presented.

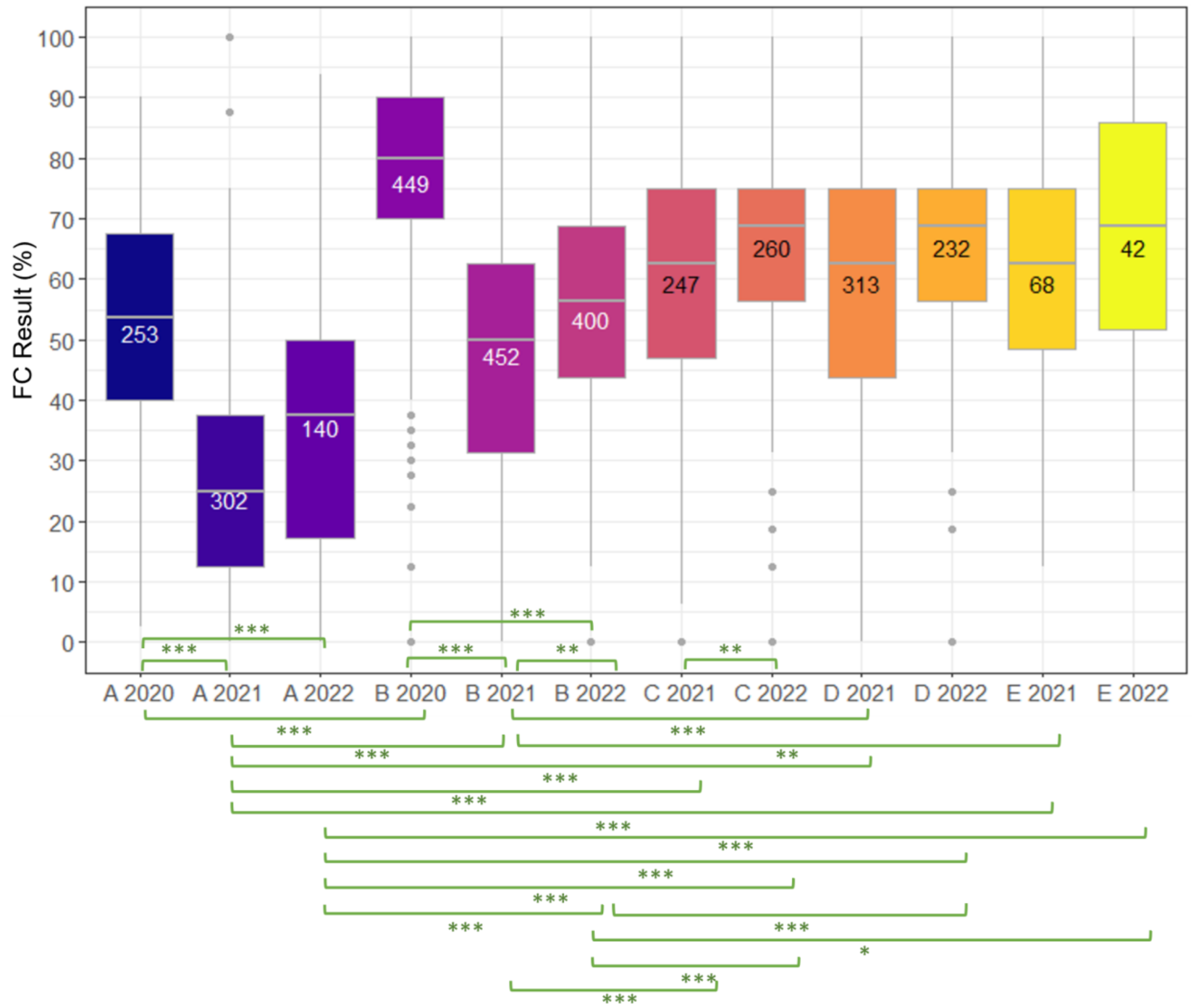

Figure 7.7: FC quiz section results with differences between cohorts identified.

Similarly to the Algebra section, there were no significant differences between the D and E modules in their FC quiz section results. Unlike both previous quiz sections there were significant differences between the A and B in 2020 and 2022, and no significant difference between A 2021 and A 2022. Below the horizontal axis, again there were significant differences between modules A and B every year, and between module A and the other modules in 2021 and 2022. In the FC quiz section, module B also had significant differences between it and all the other modules in both 2021 and

2022. However, there were no significant differences between modules C, D, and E in either 2021 or 2022. Figure 7.4 shows modules D and E had lower FC results (than the other two sections) and thus were similar to module C as in the AT section. Modules A and B had lower average results (except B 2020) as in the Algebra section.

Each module's quiz sections were tested for differences between each quiz section. Table 7.6 indicates which section scores were significantly different from each other for each module. Differences were found using a one-way repeated measures ANOVA with pairwise paired t-tests as post-hoc tests. The effect size η^2_G is given, as this is a repeated measures ANOVA. Students' performance in the AT section was significantly different to their performance in the FC section across all modules and years. The differences between Algebra and the other two sections were also significantly different in nine of the 12 cohorts.

Table 7.6: Repeated measures ANOVA results for the MathsFit quiz sections.

Module	ANOVA	AT – Algebra	Algebra - FC	AT - FC
A 2020	$F(2, 504)=181.40$, $p<.001$, $\eta^2_G=0.22$	p<.001	p=.391	p<.001
B 2020	$F(2, 896)=319.87$, $p<.001$, $\eta^2_G=0.16$	p<.001	p=.381	p<.001
A 2021	$F(2, 596)=9.27$, $p<.001$, $\eta^2_G=0.01$	p=.294	p=.003	p<.001
B 2021	$F(1.83, 827.16)=42.27$, $p<.001$, $\eta^2_G=0.03$	p=.711	p<.001	p<.001
C 2021	$F(1.91, 470.87)=8.20$, $p<.001$, $\eta^2_G=0.01$	p=.01	p=.182	p<.001
D 2021	$F(2, 624)=71.528$, $p<.001$, $\eta^2_G=0.07$	p<.001	p<.001	p<.001
E 2021	$F(1.7, 114.07)=21.96$, $p<.001$, $\eta^2_G=0.11$	p=.002	p<.001	p=.011
A 2022	$F(2, 278)=156.85$, $p<.001$, $\eta^2_G=0.19$	p<.001	p<.001	p<.001
B 2022	$F(2, 798)=563.83$, $p<.001$, $\eta^2_G=0.36$	p<.001	p<.001	p<.001
C 2022	$F(2, 518)=77.91$, $p<.001$, $\eta^2_G=0.09$	p<.001	p<.001	p<.001
D 2022	$F(1.86, 430.7)=194.75$, $p<.001$, $\eta^2_G=0.26$	p<.001	p<.001	p<.001
E 2022	$F(1.64, 67.21)=27.962$, $p<.001$, $\eta^2_G=0.29$	p=.48	p<.001	p<.001

Differences between students' two attempts at the quiz, for the students who attempted the quiz twice, were also tested via repeated measures ANOVAs. Attempt 2 results were significantly higher than attempt 1 results for all modules except A 2021 and E 2021 where the pairs of results were very similar. The test results and effect sizes are available in Appendix P.

7.6.2.2 Demographical differences

Gender had no significant association with differences in MathsFit quiz results, while international status was only associated with differences in one module C 2022 where the 30 international students had significantly higher quiz results than the 230 domestic students ($F(1)=16.10$, $p<.001$, $\varepsilon^2=0.05$, CI=0.01, 0.12). Difference tests revealed significant differences ($p<.001$) in students' MathsFit quiz results when they were grouped by converted previous grade for every module except E 2021 and E 2022. Post-hoc tests, either Tukey HSD or Dunn, revealed expected group differences with lower grades having significantly different overall quiz results than higher grades. The full list of differences is available in Table 7.7.

Table 7.7: Differences in cohorts' MathsFit quiz results grouped by previous mathematics grade.

Module & Year	**ANOVA or Kruskal-Wallis**	**Effect size (ε^2) & C.I.**	**Post hoc test**	**Differences**
A 2020	F(8)=14.01, p<.001	ε^2=0.31, (0.23, 0.43)	Tukey HSD	5>1, 6>1, 7>1, 8>1, 4>2, 5>2, 6>2, 7>2, 8>2, 6>3, 7>3, 8>3, 6>4, 8>4, 8>5
B 2020	F(7)=22.35, p<.001	ε^2=0.27, (0.21, 0.35)	Tukey HSD	7>4, 8>4, 9>4, 7>5, 8>5, 9>5, 7>6, 8>6, 9>6, 8>7, 9>7
A 2021	F(8)=10.72, p<.001	ε^2=0.20, (0.14, 0.29)	Tukey HSD	8>1, 9>1, 7>2, 8>2, 9>2, 8>3, 9>3, 8>4, 9>4, 8>5, 9>5, 8>6, 9>6, 8>7
B 2021	F(7)=15.9, p<.001	ε^2=0.20, (0.14, 0.27)	Tukey HSD	8>4, 9>4, 8>5, 9>5, 8>6, 8>7, 9>7
C 2021	F(7)=9.84, p<.001	ε^2=0.22, (0.15, 0.33)	Tukey HSD	9>4, 8>5, 9>5, 8>7, 9>7
D 2021	H(4)=50.28, p<.001	ε^2=0.16, (0.10, 0.24)	Dunn	9>6, 9>7, 9>8
E 2021	F(7)=2.05, p=.066	ε^2=0.19, (0.13, 0.43)	N/A	N/A
A 2022	F(7)=7.63, p<.001	ε^2=0.22, (0.14, 0.36)	Tukey HSD	8>2, 9>2, 8>3, 9>3, 8>4, 9>4, 8>5, 9>5, 8>6, 8>7, 9>7
B 2022	F(7)=15.36, p<.001	ε^2=0.20, (0.14, 0.29)	Tukey HSD	8>3, 9>3, 8>4, 9>4, 8>5, 9>5, 8>6, 9>6, 8>7, 9>7
C 2022	H(7)=60.13, p<.001	ε^2=0.23, (0.17, 0.34)	Dunn	9>3, 9>5, 9>6, 9>7, 9>8
D 2022	F(4)=7.19, p<.001	ε^2=0.09, (0.04, 0.19)	Tukey HSD	9>7, 9>8
E 2022	F(7)=1.94, p=0.102	ε^2=0.32, (0.20, 0.64)	N/A	N/A

The previous examination system reported by students was not as significantly associated with differences in MathsFit quiz results, with only six of the modules having significant differences, as shown in Table 7.8. All differences found were due to students who came through the QQI system having significantly lower MathsFit quiz results than their peers from other education systems.

Table 7.8: Differences in cohorts' MathsFit quiz results when grouped by previous education system.

Module & Year	ANOVA or Kruskal-Wallis	Effect size (ε^2)	Post hoc test	Differences
A 2020	H(3)=12.40, p=.023	ε^2=0.05, (0.02, 0.10)	Dunn	QQI <IB QQI <LC
B 2020	F(5)=5.06, p<.001	ε^2=0.04, (0.02, 0.09)	Tukey HSD	QQI <LC
B 2021	F(6)=5.56, p<.001	ε^2=0.06, (0.03, 0.12)	Tukey HSD	QQI < A-levels QQI < LC QQI < Other
C 2021	F(6)=3.36, p=.013	ε^2=0.07, (0.04, 0.14)	Tukey HSD	QQI < IB QQI < LC
B 2022	F(7)=2.92, p=.020	ε^2=0.05, (0.03, 0.10)	Tukey HSD	QQI < A-levels
C 2022	F(8)=4.51, p<.001	ε^2=0.12, (0.07, 0.21)	Tukey HSD	QQI < A-levels QQI < LC QQI < Other

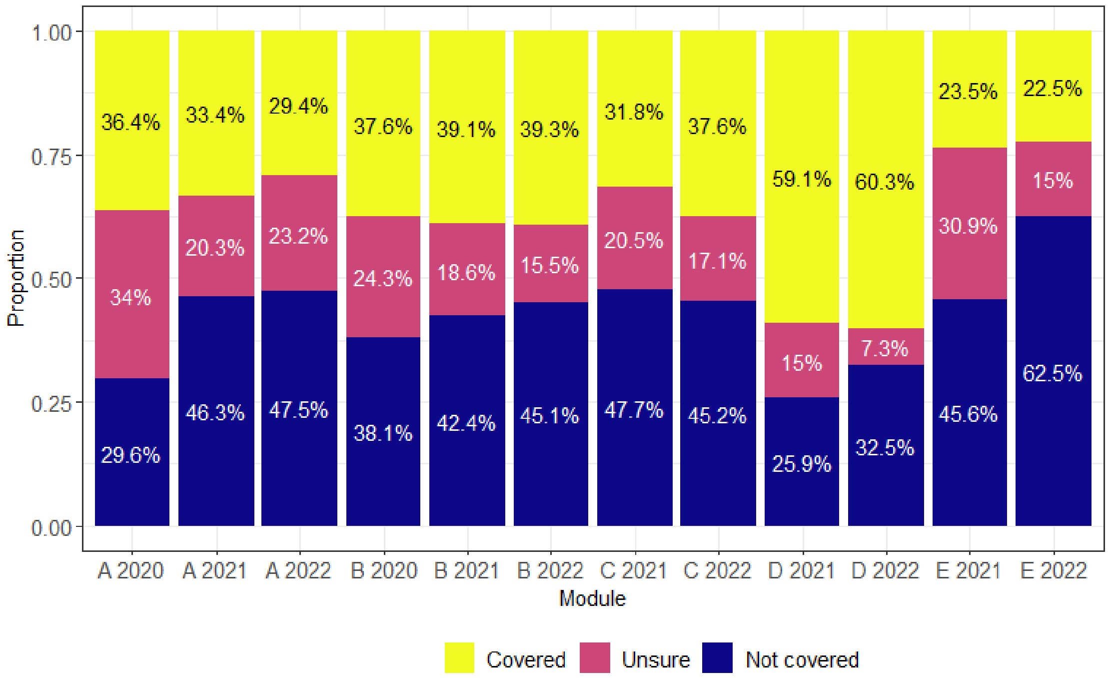

Figure 7.8: MathsFit participants' opinion of whether they covered their mathematics curriculum.

Figure 7.8 shows whether students believed they had covered their mathematics curriculum or not. Difference tests demonstrated that students' knowledge of whether they covered the curriculum was significantly associated with differing MathsFit quiz results in seven of the modules. As Table 7.9 shows, students stating that they covered the curriculum was associated with higher quiz marks, and perhaps paradoxically, sometimes even knowing that they had not covered the curriculum was significantly better, in terms of quiz results, than being unsure.

Table 7.9: Differences in cohorts' MathsFit quiz results when grouped by curriculum coverage answers.

Module & Year	ANOVA or Kruskal-Wallis	Effect size (ε^2) & C.I.	Post hoc test	Differences
B 2020	F(2)=5.04, p=.021	ε^2=0.02, (0.01, 0.06)	Tukey HSD	Not Covered > Unsure Covered > Unsure
A 2021	F(2)=6.01, p=.011	ε^2=0.03, (0.01, 0.08)	Tukey HSD	Not Covered > Unsure Covered > Unsure
B 2021	F(2)=9.74, p<.001	ε^2=0.04, (0.01, 0.09)	Tukey HSD	Covered > Not Covered Covered > Unsure
C 2021	F(2)=5.2, p=.019	ε^2=0.04, (0.01, 0.11)	Tukey HSD	Covered > Not Covered Covered > Unsure
D 2021	F(2)=4.76, p=.026	ε^2=0.03, (0.00, 0.08)	Tukey HSD	Covered > Unsure
B 2022	F(2)=5.43, p=.016	ε^2=0.028, (0.01, 0.07)	Tukey HSD	Covered > Not Covered Covered > Unsure
C 2022	F(2)=6.24, p=.008	ε^2=0.04, (0.01, 0.11)	Tukey HSD	Covered > Not Covered Covered > Unsure

No significant differences were found when comparing quiz question marks with the topics students said they had not studied via chi-squared tests. School topics were compared with similar questions, for example, the marks achieved by students in trigonometry quiz questions with whether they had covered trigonometry in their curriculum or not. This implies that students who thought they had not covered particular topics in their previous mathematics education were not negatively affected when answering MathsFit quiz questions about those topics. It was students' broader answers around coverage of the entire school mathematics curriculum that was associated with significantly different quiz results.

7.7 Discussion

UCD's MSC supports students with mathematical and statistical problems with the overarching aim to increase student success in their mathematics/statistics modules. MathsFit focuses on non-specialist first-year mathematics modules, as students in these modules may have more conflicting mathematical experiences or identities in connection with how they perceive the relevance of mathematics to their chosen degree (Alpers, 2020). MathsFit targets five modules with students from a variety of backgrounds, thus making constant changes in design and implementation necessary. Adaption of MathsFit to meet students' needs improved each year as knowledge was gained about these five modules, students within them, and their support needs. Additionally, the changing nature of higher education in terms of online, hybrid and in-person teaching and learning over the past three years (O'Shea, 2022) has allowed the development of a truly hybrid programme affording students multiple means of mathematics support engagement.

Diagnostic testing serves students by connecting to their previous mathematical learning and communicating the mathematical expectations for university (Hyland & O'Shea, 2022a). Interview analysis illustrates that this is of particular use to students who do not come from the "traditional" LC pathway (e.g., International and Mature students) to university and thus feel less sure of where they stand in terms of their competency and preparedness for university mathematics. It benefits LC students similarly, indicating commonalities between all students after a summer (or longer) without mathematics practice. Students' reaction to MathsFit aligns well with previous studies into students' views of diagnostic testing (Ní Fhloinn et al., 2014) with most student responses to the aims of MathsFit being positive. However, contrary to student views in Ní Fhloinn et al. (2014), MathsFit participants were mostly negative about the timing of its implementation.

MathsFit's main challenges are timing and further embedding within the students' first mathematics module at university. Students are involved in many different academic and social activities at the same time they are completing MathsFit. For all three MathsFit iterations reported on in this paper, first-year students had only ten weeks of teaching in their first semester due to the pandemic, instead of the usual twelve weeks. Within this tighter timeframe, aspects of continuous assessment in all four courses began earlier than usual and overlapped with MathsFit. The student-suggested earlier implementation of MathsFit is limited in possibility due to the short time frame between students' university offers being made and starting classes, and their unfamiliarity with the VLE Brightspace. While students were emailed about MathsFit, particularly the Refresher Course, the week before classes began, some were unaware of MathsFit until the first tutorial, leading to students in 2021 being caught off guard by a quiz, which was not the best first impression of MathsFit or mathematics at university. This greatly influenced the redesign of the tutorial component of MathsFit in 2022 to prevent students being caught unaware—something Ní Fhloinn et al. (2014) found was a negative aspect of students' diagnostic testing experience and Gallimore and Stewart (2014) advised against. The original emails and video introducing MathsFit seemed insufficient to make students comfortable with what MathsFit aims to offer. Using students' tutorials in the first week of classes (which were not used before the inception of MathsFit) to introduce MathsFit was much more aligned with its aim of supporting students.

The MathsFit quiz was designed with mathematical mastery in mind. Given the level of mathematics presented in the quiz, it was expected that most students would be able to answer the questions correctly with only one or two errors, therefore high thresholds for the medals were set. Students' quiz results show a performance difference between students in 2021 and their 2020 and 2022 counterparts with 2020 and 2022 participants earning higher results. This performance difference was significant in each quiz section for modules A and B, comparing 2020 with 2021, and 2021 with 2022. There was also a significant difference between module C in 2021 compared with 2022 in all three quiz sections while modules D and E performed more similarly when comparing

2021 with 2022, except in the Arithmetic and Trigonometry sections. The magnitude of these differences was not surprising given the quiz design issues in 2021. The 2021 cohort completed the quiz in-person in their first tutorials whereas the 2020 and 2022 cohorts completed it in a student chosen time and place, and there were various technical issues (poor Wi-Fi, site tracking permissions) that disrupted students in 2021.

The aim of MathsFit was and is to guide students to MSS via diagnostic testing so changing the quiz to make it more accessible and user friendly for the students was the focus of the design cycle rather than preserving a fixed format for longitudinal comparison purposes. The 2021 design changes were not as helpful as intended. The 2022 design changes were more successful and this seems to be reflected in the results of the quiz; most students had mastered the content as expected. The comparatively greater amount of time 2021 students missed in the classroom of their pre-university learning (Tusla Education Support Service, 2023), due to the pandemic restrictions in the 2020/21 academic year may also play a role in the lower 2021 results. This aligns with Hodds (2023) who reported that students entering Coventry University in 2021 had a significantly lower level of mathematical competence compared to 2020 students, based on their diagnostic test results. Reports of the competency of students who entered university in 2022 have not yet been published.

Comparing the three quiz sections, students across all modules performed worst in Functions and Calculus, and best in Arithmetic and Trigonometry (AT). It is interesting to see how students in modules A, B, and C performed worse in Algebra than in AT while students in modules D, and E performed similarly in AT and Algebra quiz sections. Module D has an entry requirement for students to achieve a H4 in Leaving Certificate mathematics or equivalent, so their stronger performance in the Algebra section, where seven of the eight questions were the same as for the other modules, is likely explained by their generally higher previous mathematics results. The results from module E, having only students from the USA, indicate that these students had similar levels of mathematical ability to the module D (Irish-based) students. The topics in the Functions and Calculus section were introduced at Leaving Certificate level whereas most of the question topics from the AT and Algebra sections were introduced at Junior Certificate level (except for modules D and E). Results relating to differences between quiz sections, especially those of module D students, are similar to those reported by Fitzmaurice et al. (2021) where Irish pre-service mathematics teachers scored well in Arithmetic and Algebra questions and somewhat poorly in Calculus questions.

Demographic and previous education information was gathered from students based on Universal Design for Learning recommended practices when performing diagnostic testing (Floretta, 2021) and to investigate if they indicated differences in students' quiz performance. Students' MathsFit Quiz results did not have differences due to gender across all modules, pointing to it being a non-discriminatory assessment in terms of gender. International students who found that MathsFit provided assurances about the mathematical level expected of them, outperformed domestic students in the MathsFit quiz in only module C in 2022 indicating international-domestic student parity in the MathsFit Quiz.

MathsFit participants provided information about their previous examination systems, the mathematical grade they achieved in that system, and how confident they were that the corresponding mathematics curriculum was covered. These factors highlighted many differences in students' MathsFit quiz results. It is unsurprising that different levels of previous mathematical achievement corresponded with significantly different quiz results. Other reports on diagnostic testing have found similar differences (e.g., Hodds et al., 2022). A diagnostic quiz aims to find areas from students' previous learning that prove difficult for individuals so remedial action may be taken.

Differences found due to students' previous examination system, where QQI students in six of the 12 participating cohorts had significantly worse MathsFit quiz results, indicate that particular support for those students may be needed. Part of the motivation for MathsFit was concern that students would not have covered all of the necessary areas of mathematics in their previous education that their university mathematics modules seek to build upon. The differences in MathsFit quiz performances in seven cohorts when grouped by students' answers about curriculum coverage, indicate the concern was not unfounded. A revealing result was that, for some cohorts, being unsure about what mathematics topics they had been taught aligned more with lower results than those who knew what areas they had missed.

7.8 Future plans

MathsFit continued in September 2023 and is scheduled to run again in September 2024. Hosting of the quiz and refresher course returned to Numbas, as the commercial nature of Bolster Academy had too high a financial cost. With further developments in Brightspace and Numbas compatibility and the redesign of the first tutorials so that students do not take the quiz in large numbers simultaneously, Numbas and Brightspace worked sufficiently enough together for the purpose of MathsFit. The development of the Numbas "Diagnosys" system (Lawson-Perfect, 2021) is being closely monitored by researchers in the area of diagnostic testing and support. This tool uses a knowledge graph and diagnostic algorithm to establish students' mathematical proficiency in as few questions as possible by basing the selection of the next question the student answers on their previous answer(s). A mastery mode is also available where students' incorrectly answered questions reappear later in the quiz and the quiz ends once all questions are correctly answered. Shearman et al. (2024) described the implementation of Diagnosys in Western Sydney University, noting the greater efficiency and personalisation the system offers students and the potential for both formative and summative assessment. The Diagnosys system is being considered for MathsFit based on the greater quality of personalisation it offers, in line with the student-centred design of MathsFit.

At the time of writing in June 2024, discussions at school level are ongoing with MSC management and module coordinators interested in using MathsFit in their module, and on how best to further embed it within participating modules. Module A's module coordinator, who previously did not want any continuous assessment credit attached to MathsFit has agreed to award their students 2% for participating in MathsFit. Hopefully these discussions and the return to an 11-week-long, if not 12-week-long, semester for first-year students will resolve the timing issues identified with MathsFit in this paper.

Future work on the quiz data will include analysis of students' marks per question to identify the worst and best answered questions over the three years. Discriminant and correlation analyses were conducted in 2020/2021 to reduce the quiz from 30 questions to 24, and brief analysis of results per question took place each year to identify topics for MSC tutors to focus on if students from MathsFit attended the MSC but did not have particular questions. However, a full statistical analysis to identify poorly and well answered questions has not taken place. A comparison of answers to the 14 core questions across all five modules' different versions of the quiz, could be made from this dataset. Closer comparison with the findings of Fitzmaurice et al. (2021) on students' performances in particular topics may then be possible. The brief topic analyses conducted on the MathsFit data suggest "indices" may also be difficult for UCD first-years, as was found by Ní Fhloinn (2009) for Dublin City University students. Investigation into students' confidence in their answers is also planned. Data about students' confidence in their answers were gathered in 2021 and 2022. This will allow comparison of students' results with how they felt they performed.

7.9 Conclusion

This paper tracks the development of the MathsFit support programme from 2020 to 2022 with results from 3,268 student participants. The difficulties of integrating a new support programme into established mathematics modules, particularly in the context of the COVID-19 pandemic learning environment have been highlighted alongside the benefits of MathsFit. Analysis of students' performance in the MathsFit Quiz revealed struggles with Functions and Calculus for many students and with Algebra for some. Collection and analysis of students' demographic data indicated the MathsFit Quiz was non-discriminatory in terms of gender and international status and confirmed differences in students' mathematical proficiency based on their previous mathematical achievement, prior educational pathway and knowledge of their previous mathematics curriculum. MathsFit is both a student support and a research programme advising first-year students of their support needs and generating empirical evidence about those students' mathematical proficiency and support use.

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8 Measuring student support engagement: Participation in MathsFit, a diagnostic and support programme

Abstract

Students' engagement with mathematics support offered by MathsFit, a mathematics diagnostic and support programme for first-year non-specialist students, is the focus of this paper. MathsFit has been in operation since September 2020 and includes a diagnostic test that triggers personalised emails suggesting support for students who need it. Support offered includes the Refresher Course, a mix of videos and online practice questions, and visits to the Maths Support Centre. Engagement in this support by 3,268 student participants between 2020 and 2022 will be examined with reference to their demographics. Results indicate a low MSC visit rate from most students and increasing use of the RC over the three iterations of MathsFit. Student use of the Refresher Course indicated a slight preference for practice questions over videos and a tendency to focus on topics they scored well in the MathsFit quiz instead of those in which they performed poorly. Seven years of MSC visits by students from the five participating modules and two other first-year modules highlight the drop in MSC visits due to the move online. While MathsFit participants had higher rates of MSC attendance than the comparison modules, historical comparison indicated disappointing student engagement with the MSC. A broad discussion of these results with reference to previous research about the interaction between diagnostic testing and support use will be presented. Conclusions on students' engagement with the support offered by MathsFit during 2020–2022 will be drawn.

8.1 Introduction

MathsFit is a mathematics diagnostic and support programme for first-year non-specialist students which commenced in September 2020 in University College Dublin (UCD). It was designed to inform students and staff of students' mathematical proficiency levels and guide students to support, if necessary. The support offered by MathsFit includes the already existing Maths Support Centre (MSC) in UCD and a newly created online Refresher Course. The aim of this paper is to explore students' engagement with the MathsFit supports during the first three years of the programme, 2020-2023, with reference to students' demographics. The first year of MathsFit involved two modules of students from the Agriculture and Health Sciences, and Business degrees and these two modules were joined by three modules from the Science and Engineering degrees in the second and third year of MathsFit. The engagement of these twelve cohorts of students, totalling 3,268 participants, is the focus of the presented analysis. Students' support engagement will be considered by module and year but also by group, meaning groups created by students' previous education, gender, and other factors. Engagement with the MSC by students from these modules in 2015-2019 will also be considered to examine how, if at all, MathsFit changed MSC engagement. MSC engagement from two modules that were not involved in MathsFit is also considered for comparison purposes. The research questions answered by this paper are:

1. How did MathsFit participants engage in the suggested mathematics support and how does this compare to MSC engagement prior to the establishment of MathsFit?
2. Are there statistically significant differences associated with gender, previous mathematics education or other factors in students' support engagement?

8.2 Literature review

Diagnostic tests aim to help students identify gaps in their mathematical knowledge and advise them on actions to rectify those gaps, usually through attending an MSC, using online or paper resources, or other forms of MSS. Ensuring students engaged in any necessary follow-up support, and interpreted the results as university staff and/or the diagnostic test designers intended, is therefore extremely important. However, this can be a difficult task, unsurprising given the issues discussed in Mullen et al. (2024) about evaluating MSS impact on students. In some diagnostic programmes the test is used to place students in certain classes (Akverd & Kinnear, 2023; Harper & Reddy, 2013) or students are tested repeatedly until they pass as part of the follow-up process (Turner, 2008; Carr et al., 2013; Marjoram et al., 2008). These designs necessitate students engage with their diagnostic test results and ensure understanding of the results, though perhaps in binary terms of "in class A/in class B" or "pass/fail". With others, for example, Lee and Robinson's (2005) paired questions design where engagement in follow-up support was not as high as desired because students thought they had adequate knowledge of a skill when they got only one of two questions correct, students do not interpret results or engage in support as desired. Sheridan (2013) also reported a low uptake of follow-up support in Dublin Institution of Technology (now Technological University Dublin). Therefore, evaluation of students' use of follow-up support based on their diagnostic results must be placed within the context of the design of the diagnostic system.

Students' reasons for non-engagement with mathematics and statistics support (MSS) are usually structural in nature, such as timetabling issues or not knowing MSS was available (Mac an Bhaird et al., 2013; O'Sullivan et al., 2014; Symonds et al., 2008). However, fear is also a key factor in non-engagement, perhaps being hidden under those structural reasons (Mac an Bhaird et al., 2013; Symonds et al., 2008). More recently, Gokhool (2023) explored reasons for engagement and non-engagement with an MSC, and methods of encouraging engagement, in her PhD thesis. There was a particular focus on demographic factors and the effect of mathematics anxiety (Richardson & Suinn, 1972). Gokhool's (2023) findings via a hurdle model using 2020/21 data, suggest female, mature, disabled, and international student groups are significantly more likely to engage than not in MSS than their counterparts (male, non-mature, non-disabled, and domestic student groups) while domestic students are significantly more likely to make repeat visits than international students. The survey of Irish non-specialist mathematics first-year students about MSS (O'Sullivan et al., 2014) also found similar results about females and mature students' MSS use with more specifics presented in Ní Fhloinn et al. (2016) and Fitzmaurice et al. (2015) respectively.

Gokhool's (2023) results also indicate that mathematically anxious students with high levels of mathematical resilience were predicted to use MSS more though engagement starts to decrease when students have high levels of mathematics anxiety and only medium levels of mathematics resilience. The addition of students' mathematics anxiety to the hurdle model resulted in gender, disability, and age no longer being significant predictors while course type, ethnicity and mathematics anxiety were significant predictors. Gokhool (2023) also found that students gave affective reasons (fear of judgement, fear of the unknown, fear of embarrassment) about their lack of engagement with MSS, preferring to seek support from the internet, lecturers or peers instead. Fear of failure, however, prompted students to engage. In the diagnostic testing literature, on the other hand, students who are advised to avail of follow-up support based on their diagnostic test result are often deemed at-risk of failure, but engagement does not necessarily follow (Burke et al., 2012; Sheridan, 2013).

Engagement with mathematics and statistics support in recent years has changed dramatically with the necessary move to online support due to the COVID-19 pandemic. Hodds (2020) first reported on the large decrease in support use based on a survey of MSS practitioners with responses from 78 higher education institutions including 19 outside the UK. Mullen et al. (2021a; 2022), Gilbert et al. (2021), and Johns and Mills (2021) added greater evidence about this issue, noting concerns about students who needed MSS but were unaware of, or unable to access MSS online. Various attempts to engage students with support such as Mac an Bhaird et al. (2021) creating study groups have had little effect. Practitioners and students noted a preference for in-person support (Mullen et al., 2021a; Gilbert et al., 2023) which may explain some of the decreased use online. However, benefits of online support were identified and online support can work (Mullen et al., 2021a). As expected by practitioners most MSS provisions now operate some form of hybrid support (Mullen et al., 2021a; Gilbert et al., 2021; Gilbert et al., 2023) as it is preferred by students (Mullen et al., 2023). The balance of in-person and online is still under evaluation in most institutions as noted in Mullen et al. (2023) where student opinion pointed to a hybrid format being suitable but with an in-person preference in University College Dublin. Yet, within months of the survey online attendance and therefore the hours it was offered had reduced. Anecdotally, MSS engagement has still not recovered.

8.3 Method

8.3.1 MathsFit Design

MathsFit was designed as an early intervention for students with their participation – exploring the Refresher Course, attempting the MathsFit quiz, receiving feedback emails with support suggestions – scheduled for the first two weeks of their first semester at university. Students were alerted by email about MathsFit in the week prior to the semester beginning and from 2021 onwards attended a tutorial about MathsFit in their first week. They had two attempts at the MathsFit quiz which has three sections: Arithmetic and Trigonometry, Algebra, and Functions and Calculus. A personalised feedback email was sent to each student after they completed a quiz attempt with their score in each section in medal form (Gold, Silver or Bronze) and accompanying support suggestions for each section – Gold meaning no support suggested, Silver suggesting engagement with the Refresher Course, and Bronze recommending a visit to the MSC and engagement with the Refresher Course. Those who received two or three Bronzes were invited to join a study group with other students from their module in the MSC. Further details of how students participated in MathsFit and the design evolution of MathsFit is in Mullen and Cronin (n.d.) (Chapter 7).

Part of the design evolution of MathsFit was the development of the Refresher Course (RC) from existing videos and worksheets from MSC resources in 2020 to include interactive online practice questions from 2021 onwards. The RC was hosted in Moodle, a virtual learning environment, in 2020, and changed to Numbas, a community-led online mathematics assessment system (Lawson-Perfect, 2012), through integration with Brightspace, UCD's virtual learning environment, in 2021 as student access to the RC was offered before their first attempt (to access Moodle students needed a key provided in their first feedback email). In 2022 the quiz and RC practice questions moved to

Bolster Academy, a commercial online learning and assessment environment which offered greater technical support. The RC videos remained in Brightspace with links to access Bolster Academy. Due to the differences between Numbas and Bolster Academy, practice questions were slightly different in style. The practice questions in 2022 were chosen from Bolster Academy's pre-existing set of Basic Math package questions to align with the quiz questions, module content, and prior learning whereas the 2021 Numbas questions were adaptions of Western Sydney University resources and freely available questions with some newly created questions. Some elements of the Bolster Academy RC were interactive presentations instead of practice questions due to no suitable questions being available. The differences in the number of questions in the RC from 2021 to 2022 is available in Appendix R. All versions of the RC were organised into the same three sections as the quiz: Arithmetic and Trigonometry, Algebra, and Functions and Calculus.

The MSC at UCD opened in 2004 and until March 2020 operated as an in-person drop-in service based in the central library of the university. It is staffed by postgraduate tutors and final-year undergraduates. From March 2020 to May 2021, during which time the first iteration of MathsFit occurred, it operated fully online through Brightspace Virtual Classroom, the video conferencing element of Brightspace. Students booked a 30 minute appointment through the MSC website and were sent access instructions via email. During 2021 (and the second iteration of MathsFit) the in-person centre re-opened but with limited capacity so appointments were still necessary. Online support was also available, with approximately 30% of available appointments being online and the others in-person. Online support availability reduced to approximately 20% during the third iteration of MathsFit, in 2022, and in-person drop-ins were allowed, though students with appointments were prioritised. In their MathsFit feedback emails, if the MSC was recommended, students were invited to make an appointment and provided with a link to do so. In 2021, six evening MathsFit online MSC sessions occurred during the two weeks in which students could attempt the MathsFit quiz. In 2020 and 2022, the first available MSC appointments were only in the second week of MathsFit. The study groups, for students who scored two or more Bronzes, were held in the MSC with a tutor leading the group each week. Students were contacted by email by the lead researcher to arrange a suitable time. Groups consisted of three to five students from the same module.

8.3.2 Data Collection

Table 8.1 presents the number of participants in each element of MathsFit relevant to this paper. These participants were in five modules: Module A (students studying Food Science or Agriculture), Module B (Business students), Module C (students studying Biology or Chemistry), Module D (Engineering students), and Module E (American exchange students studying engineering).

Table 8.1: MathsFit participants' engagement.

MathsFit element	2020	2021	2022	Total
Pre-survey	702	1,435	1,131	3,268
(% of total registrations)	(81.25%)	(86.55%)	(67.97%)	(78.07%)
Quiz Attempt 1	702	1,417	1,052	3,171
Quiz Attempt 2	343	678	485	1,506
Refresher Course use	189	955	1,043	2,235
MSC visits	183	179	175	537
Study group participants	16	3	1	20

The pre-survey, which students answered before attempting the quiz, asked for students': consent to participate in the research study, gender, international or domestic status, previous mathematics examination taken (e.g., Leaving Certificate, QQI), and achieved grade. The pre-survey also inquired whether students thought they had covered their mathematics curriculum, were unsure, or thought they had not. Students selected, from a list, the topics they had not covered, if appropriate. The pre-survey questions are included in Appendix M. Students' quiz attempts prompted feedback emails that suggested support use if applicable (quiz questions are available in Appendix J and the feedback emails are available in Appendix K). Data on students' use of the Refresher Course was recorded by the host website of the Refresher Course. Brightspace (host in 2021 and 2022) and Bolster Academy (2022 host) provided the amount of time students spent on each item (video, practice question), while Moodle (2020 host) did not, merely recording if a student clicked on an item. Student visits to the MSC were recorded by the MSC management system which documents the time and date students arrived, how long they stayed for, how long they spent with a tutor and what module they sought help for, with tutor feedback comments relayed to the relevant module coordinator. MSC data in this paper were provided by the MSC manager, for the students in the five MathsFit modules who consented to be involved, and for students in the these five modules in previous years. MSC data from two other modules, who were not targeted by MathsFit, was also collected to be analysed for comparison with MathsFit participants. Consent from non-MathsFit participants was gained via students who visited the MSC agreeing to their data being recorded upon MSC sign in.

There were a range of missing data, with different strategies implemented to reduce their effects. A number of participants missed a question or part of a question in the pre-quiz survey which gathered students' demographics. Pre-survey variables' missing data levels ranged between 0.03% and 6.52%. Where possible, missing survey data were estimated via mean imputation, but most questions were not similar enough for this strategy to be sensible. Pairwise deletion of missing data occurred—students with missing data were still kept in the dataset and were removed if necessary, depending on the analysis being conducted. Sample sizes are therefore presented alongside results.

Regrettably, a software error resulted in the loss of RC video data per student for module C in 2021. As statistical tests, presented later, showed significant differences between the same module in different years and different modules within the same year, the missing data for the module C 2021 cohort was not computed based on other cohorts' data. Average time spent on each video by module C 2021 students was available from Brightspace and the sum of those average times was 88.46 minutes, but this was an average per visit instead of per student. It does not account for the same students visiting a video multiple times, or for the students who did not visit a video. To avoid greater inaccuracy by the use of estimation based on the Brightspace averages, RC total time was calculated solely based on total time spent on practice questions by C 2021 students. With the loss of video data per student it is also unknown if any C 2021 students used only the videos in the RC, used only the RC practice questions, used both videos and practice questions, or used neither. Both RC total time and the number of RC users for cohort C 2021 are most likely an underestimation of the true data. Additionally, Bolster Academy did not provide time measurements for students' interactions with non-question parts of the RC. For example, how long students' viewed the differentiation interactive presentation that students in modules, A, B, and C were offered to remind them how to differentiate (as differentiation questions available in Bolster Academy were too advanced for these students) is unknown. This means the time measurements for the practice questions in 2022 may be a slight underestimation.

There were 147 (4.50%) students in the dataset who consented to participate but did not complete the quiz, the majority being in module A where there was no assessment credit incentive. These students were included in the dataset as most used the RC and/or the MSC, so analysis of those variables could be completed for them along with the pre-survey data they provided. The lower participation rate of 44.2% of students in module A in 2022 meant that the sample for that module may not be as representative as desired. The other 11 cohorts had participation rates of 71.27%–92.67%. Note, as MSC data fall under a different consent and ethics protocol, the full population of the participating modules was used in individual analysis of MSC data. Elsewhere, the MathsFit sample of the modules was used.

8.3.3 Data Analysis

A key part of the MathsFit support engagement analysis was difference testing of a grouped numerical variable, for example, comparing MSC visit counts by gender. As will be presented in the results section, most data did not follow the normal distribution. Both time in the RC and number of MSC visits were more similar to the Poisson or negative binomial distributions so the Kruskal-Wallis test (Kruskal & Wallis, 1952) was performed due to its potential power using non-normal data (Sheng, 2008).

The procedure used to calculate Kruskal-Wallis tests was as follows:

1. If testing for differences due to other variables (demographic or previous education, e.g., gender), that is, not for differences between modules, the data were filtered to one module and year, for example, B 2021.
2. The Kruskal-Wallis test was calculated for the two variables.
3. The p-values resulting from all tests were adjusted using the False Discovery Rate (Benjamini & Hochberg, 1995).
4. Adjusted p-values were used to identify which Kruskal-Wallis tests had significant results, where $p<.05$.
5. Effect sizes, using ε^2 were calculated (King et al., 2018).
6. If the test was significant the Dunn post hoc test was run to find the differences between groups.

To test differences between connected variables, for example, participants' use of the three sections of the Refresher Course, Friedman tests with post-hoc pairwise Wilcoxon tests with adjusted p-values were used. The False Discovery Rate (FDR) was chosen as the p-value adjustment method for all adjustments because of its potentially greater power (Benjamini & Hochberg, 1995). Effect sizes were calculated using ε^2 to reduce positive bias due to sample size. Kendall's W value is provided for Friedman test results.

8.4 Results

8.4.1 Participants' Demographics

Over the three iterations of MathsFit reported on in this paper, 3,268 students consented to participate in the research. The demographic data presented and analysed in this paper is also studied in Mullen and Cronin (n.d., Chapter 7). Table 8.3 presents the number of MathsFit participants, and by percentage their gender, international status and how many of them completed the Leaving Certificate, the Irish secondary school terminal examination, by module and year. Students were asked in the pre-survey to state their gender (Male, Female, Non-binary, or Prefer not to say), whether they were international or domestic students, and what previous examination they had taken (e.g., Leaving Certificate, A-levels). Table 8.4 presents the previous education systems other than the Leaving Certificate students had completed.

Table 8.2: Demographics of MathsFit participants

Module & Year	Participants	Female, Male	International	Leaving Certificate
A 2020	253	59.29%, 40.32%	1.98%	94.07%
B 2020	449	48.11%, 51.67%	7.80%	88.64%
A 2021	335	61.79%, 37.31%	3.58%	87.76%
B 2021	458	47.16%, 52.18%	7.86%	87.34%
C 2021	258	64.73%, 34.88%	9.30%	84.50%
D 2021	316	28.16%, 70.89%	8.23%	91.77%
E 2021	68	44.12%, 54.41%	100%	0.00%
A 2022	179	63.13%, 35.75%	3.35%	92.74%
B 2022	413	52.30%, 47.46%	11.13%	86.44%
C 2022	263	66.92%, 29.28%	11.41%	78.33%
D 2022	234	28.63%, 70.51%	5.98%	94.02%
E 2022	42	59.52%, 33.33%	100%	0.00%
Total	3,268	51.16%, 47.89%	10.53%	85.28%

Table 8.3: MathsFit participants' pre-university education.

Module & Year	A-level	GCSEs	International Baccalaureate	MSAP[16]	QQI	SATs[17]	UCD Access	Other
A 2020	0.00%	0.00%	0.40%	0.00%	3.95%	0.00%	0.00%	1.58%
B 2020	0.45%	0.45%	0.89%	0.00%	3.79%	0.00%	0.00%	5.79%
A 2021	0.30%	0.00%	0.60%	1.19%	7.46%	0.60%	0.30%	1.79%
B 2021	1.09%	0.44%	0.87%	0.00%	4.59%	1.53%	0.00%	4.15%
C 2021	0.78%	0.00%	1.94%	0.00%	5.43%	1.55%	1.93%	3.88%
D 2021	0.95%	0.32%	0.32%	0.00%	0.00%	0.95%	2.22%	3.48%
E 2021	0.00%	0.00%	7.35%	0.00%	0.00%	55.88%	0.00%	36.76%
A 2022	0.56%	0.00%	0.00%	1.12%	3.35%	0.00%	0.00%	2.23%
B 2022	1.69%	0.24%	0.97%	0.00%	3.63%	1.45%	0.73%	4.84%
C 2022	1.52%	0.76%	2.28%	0.38%	7.98%	1.90%	1.52%	5.32%
D 2022	0.85%	0.00%	0.85%	0.00%	0.00%	0.00%	0.43%	3.85%
E 2022	0.00%	0.00%	14.29%	0.00%	0.00%	52.38%	0.00%	33.33%
Total	0.83%	0.24%	1.22%	0.21%	3.95%	2.66%	0.64%	4.96%

Figure 8.1 shows students' mathematical achievement based on their most recent mathematics examination (pre-university) converted to a scale of 1-9. A score of 9 is equivalent to a

[16] Mature Students Admissions Pathway
[17] Scholastic Aptitude Test (USA education system)

Leaving Certificate H1 (90-100%), an A-level A* and a "7" in International Baccalaureate, 8 is equivalent to a Leaving Certificate H2 (80-89.99%), and so forth. Conversions to the nine point scale were based on UCD entry requirements (University College Dublin, 2021) for all participants' examination systems. The conversion table is available in Appendix Q. Note, for ease of presentation in Figure 8.1, the years in the horizontal axis are shortened, for example, A 21 denotes module A in the year 2021. Due to the different courses' entry requirements, a difference in the spread over the grade scale 1-9 is visible between modules. For the majority of students[18] module A requires at least H7 or O6 ("3" or "1"), modules B and C require at least a H6 or O2 ("4"), and module D requires at least a H4 ("6") in Leaving Certificate mathematics. Students in module E are expected to have reached a similar standard as module D.

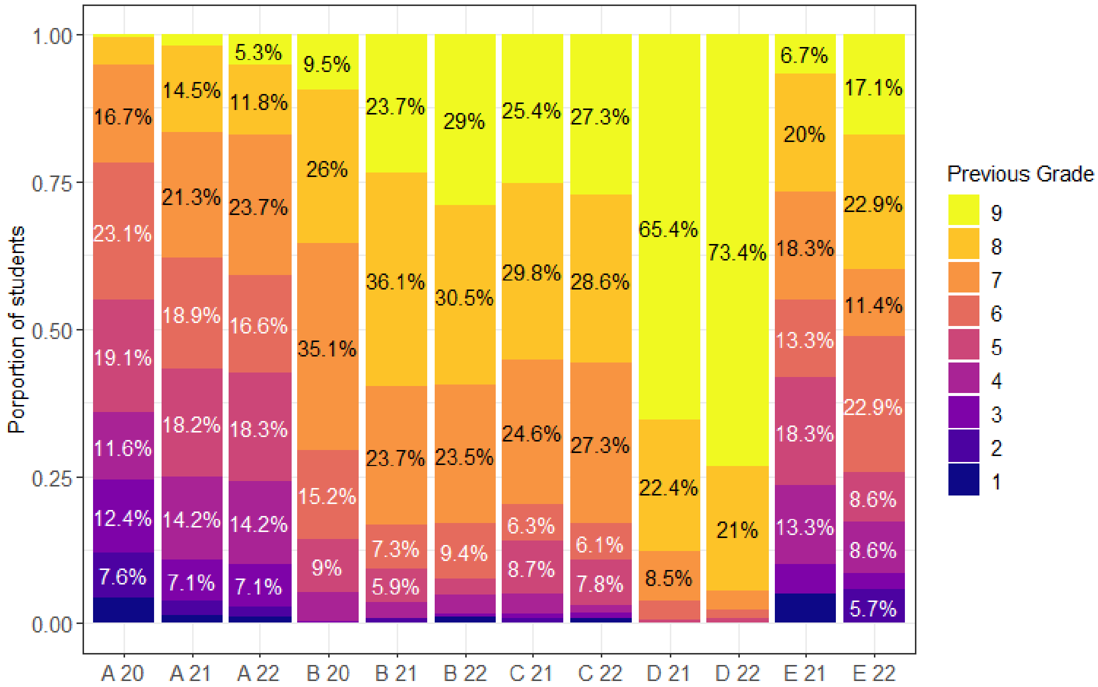

Figure 8.1: MathsFit participants' converted previous mathematics grades.

Students were also asked if they felt they had covered the mathematics curriculum in their previous education, given the ongoing school and education institutions closures due to the pandemic. Figure 8.2 presents their answers by module and year. As all module E students are American registered students, the lack of surety in whether they had covered their curriculum may have been influenced by the differences in Irish and American curricula. Among modules A, B, C and D, where the vast majority of students had just completed their Leaving Certificate examinations, it is interesting to note those in module D, which had the highest mathematical entry requirements, were most sure that they had covered their mathematics curriculum.

[18] Schemes such as HEAR and DARE allow students entry to a course with lower entry requirements.

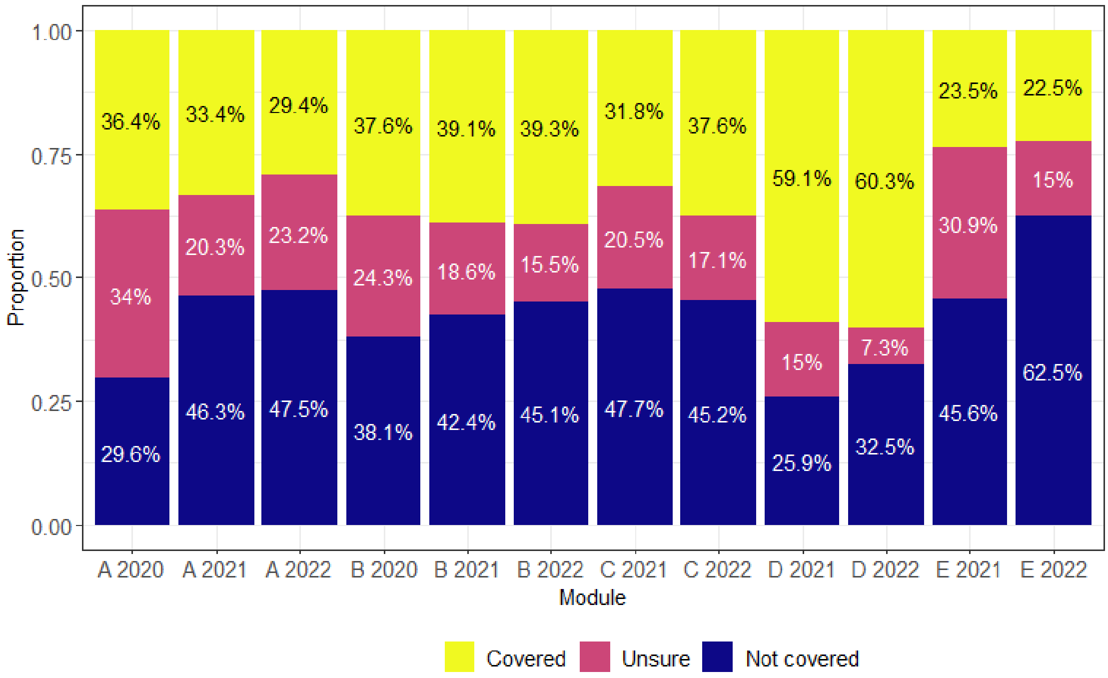

Figure 8.2: MathsFit participants' opinion of whether they covered their mathematics curriculum.

8.4.2 Refresher Course engagement

Based on the MathsFit Quiz Attempt 1 results, students were advised to use the Refresher Course for a quiz section if they scored a Silver or Bronze in that section. Table 8.4 presents the number and percentage of participants per module and year that were advised to use the Refresher Course (RC). Students who received a Silver or Bronze in a quiz section – those who scored less than 90% in 2020 and 2021 and less than 87.5% in 2022 – were recommended to engage with the RC. As quiz analysis presented in Mullen and Cronin (n.d., Chapter 7) revealed, many students struggled with the Functions and Calculus section of the MathsFit Quiz, causing the majority of students to be recommended to engage with the RC for at least the Functions and Calculus section, hence the high percentages presented in Table 8.4.

Table 8.4: Number and percentage of students recommended to use the Refresher Course based on their first attempt at the MathsFit quiz.

Module	2020	2021	2022	Total
A	100.00% (253)	98.51% (330)	78.21% (140)	94.26% (723)
B	96.21% (432)	98.47% (451)	92.01% (380)	95.68% (1,263)
C	NA	97.67% (252)	91.25% (240)	94.43% (492)
D	NA	99.68% (315)	87.18% (204)	94.36% (519)
E	NA	100% (68)	80.95% (34)	92.73% (102)
Total	97.58% (685)	98.68% (1,416)	88.24% (998)	94.83% (3,099)

Table 8.5 presents the percentage of students who used the Refresher Course (RC) by module and year. It shows the increase in uptake of the RC over the three years of MathsFit, particularly in

modules A and B. Increasing RC use was a focus of the design evolution reported in Mullen and Cronin (n.d., Chapter 7), with strategies including greater video curation, introduction of practice questions, change of RC host website, and allowing students access to the RC before their first quiz attempt. RC use was only prompted by feedback emails in 2020 (i.e., it could not be accessed prior to taking the MathsFit quiz), as students needed the Moodle key provided in the email to access the RC. This restricted access is reflected in students' engagement with the RC in 2020 recorded in Table 8.5. However, in 2021 and 2022 the RC was accessible through Brightspace (where the practice questions, in Numbas and Bolster Academy, and videos were located) and was available before students took the quiz. This greater access prompted greater engagement, particularly from students in modules B,C, D, and E who earned continuous assessment credit for completing the MathsFit Quiz and were thus more incentivised to use the RC. Unfortunately, at the time of data collection, Brightspace and Bolster Academy did not record the dates of each visit students made to the Refresher Course, just the last date accessed in Brightspace and time spent in both sites. Thus, students' use of the RC could not be separated between pre-quiz and post-quiz use.

Table 8.5: The percentage and number of students who engaged in the Refresher Course by year and module.

Module	2020	2021	2022	Total
A	16.60% (42)	42.69% (143)	78.21% (140)	42.37% (325)
B	33.33% (147)	63.10% (289)	95.40% (394)	62.88% (830)
C	NA	81.01% (209)	92.02% (242)	86.56% (451)
D	NA	79.75% (252)	96.15% (225)	86.73% (477)
E	NA	91.18% (62)	100.00% (42)	94.55% (104)
Total	26.92% (189)	66.92% (955)	92.22% (1,043)	66.92% (2187)

Time spent in the RC is the focus of the next analysis section. RC use in 2020 is not explored as time measures were not gathered . Percentages calculated using binary measurements of the topics students viewed, did not allow for inference of the length of time students spent on each page. As time spent is key in development of mathematical skills, only the years where time spent could be measured are analysed.

8.4.2.1 Time spent in the RC

The average time per student spent in the RC (excluding students who did not engage (33.08%) and those from 2020, as time could not be measured then, giving 1,998 RC users from 2021 and 2022) was 109.39 minutes. The standard deviation was 261.67 minutes. There were a number of outliers identified for RC time. A student in E 2022 spent 5053.30 minutes (84.22 hours) in the RC and a student in B 2022 spent 3640.77 minutes (60.68 hours) in the RC. Apart from these two, all other students spent less than 2400 minutes (40 hours) in the RC. Datum values greater than the mean plus three standard deviations were excluded from Figure 8.3 and difference testing. This meant the removal of 43 students who engaged with the RC in 2021 and 2022. This excluded group was made up of one A 2021, three A 2022, 12 B 2022, 10 C 2022, eight D 2022 and nine E 2022 students. Their total time in the RC ranged from 946.28 minutes (15.77 hours) to 5053.30 minutes (84.22 hours).

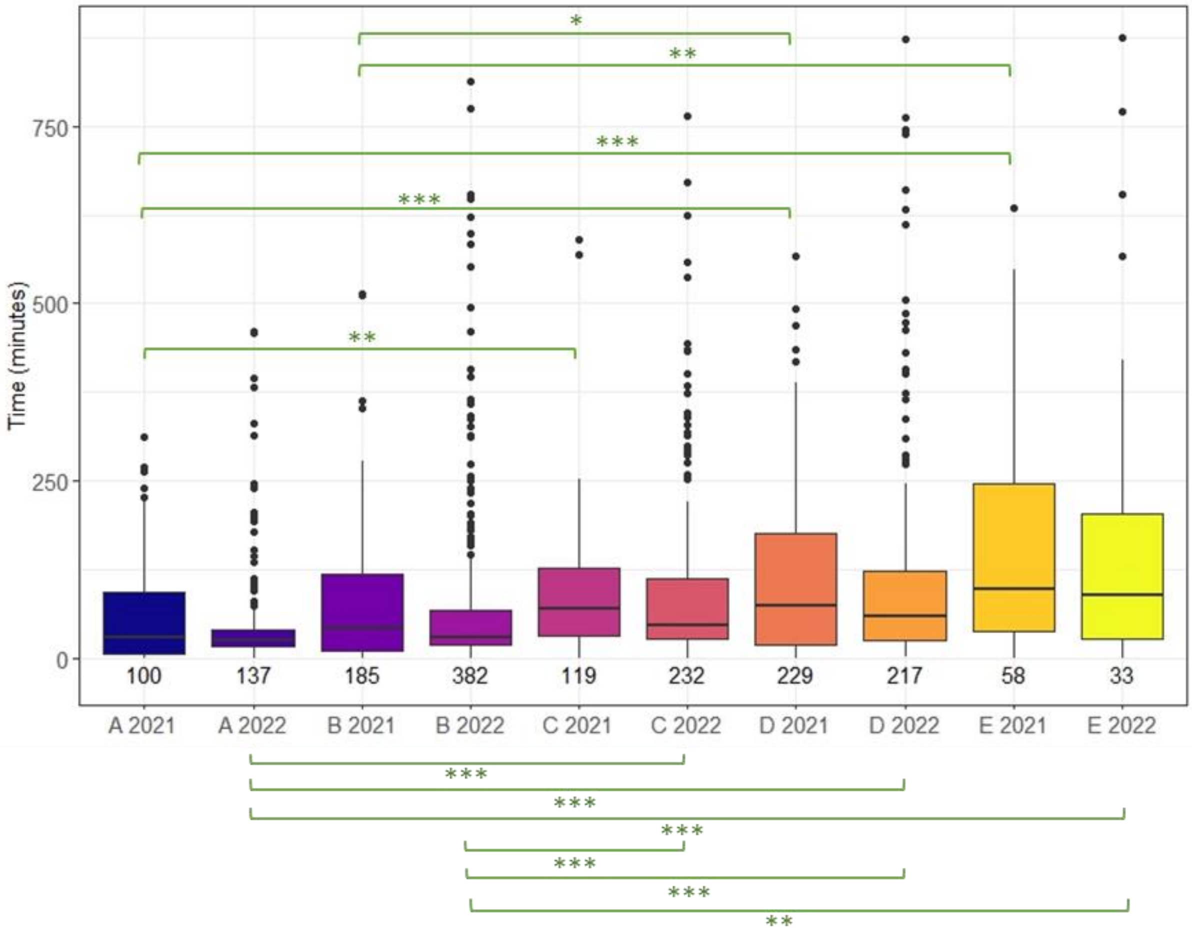

Figure 8.3: MathsFit cohorts' total time spent in the Refresher Course by year and module.

The time students spent in the RC, shown in Figure 8.3, was significantly different by module ($H(9)=101.12$, $p<.001$, $\varepsilon^2=0.06$, CI=0.04, 0.09). The Dunn post hoc test revealed the differences shown in Figure 8.3 with three asterisks indicating p<.001, two asterisks meaning p<.01, and one asterisk p<.05. Only differences between years of the same module and modules within the same year are shown with 2022 differences shown below the horizontal axis. The numbers just above the horizontal axis are the number of students in each respective module included. Comparing between modules, Figure 8.3 shows module A students spent significantly less time in the RC than students in modules C, D and E in both 2021 and 2022. Module B students also spent significantly less time in the RC than students in modules D and E in both 2021 and 2022 and significantly less time than module C students in 2022. Module C students spent significantly more time in the RC than module D students in 2021 only. Modules D and E acted similarly with regard to time spent in RC in both 2021 and 2022. Students in the modules with the highest prerequisites spent more time in the RC.

The total time spent by students on RC practice questions was tested to account for the module C 2021 missing RC video data. This was similarly significant ($H(9)=165.99$, $p<.001$, $\varepsilon^2=0.10$, CI=0.08, 0.13). Figure 8.4 presents the differences between modules and years. All differences found for RC total time were found for time spent on RC practice questions except for the difference between B 2022 and D 2022. Additional differences were found between B 2021 and B 2022, B 2021 and C 2021, and C 2021 and D 2021. There is a clear difference in RC practice question engagement between modules C, D and E, and modules A, and B.

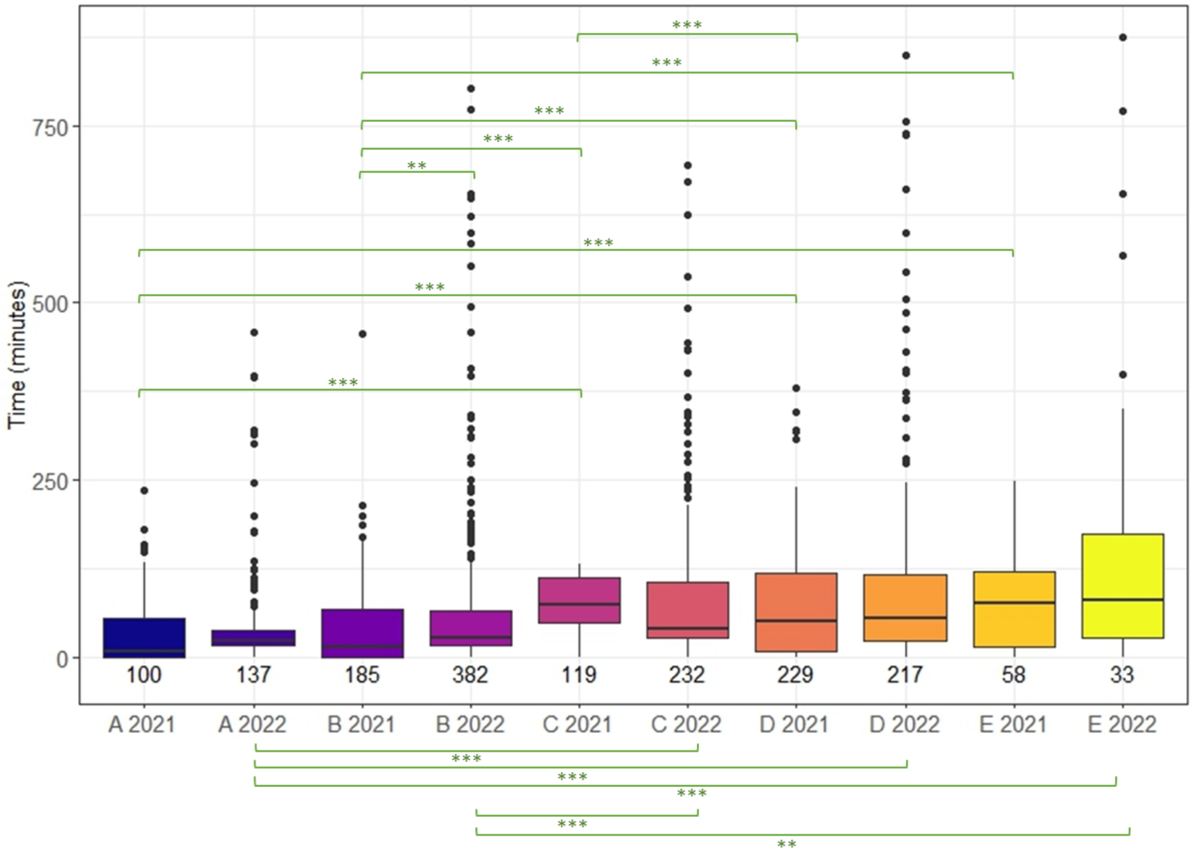

Figure 8.4: MathsFit cohorts' total time spent on Refresher Course practice question by year and module.

Within each module for the group of students presented in Figure 8.3 and Figure 8.4 (i.e., those who used the RC in 2021 and 2022 with outliers removed), non-parametric Friedman tests were run to examine how much time students spent in each RC section with post-hoc pairwise Wilcoxon tests. Table 8.6 presents the test results. Columns three, four and five indicate which median section time is significantly higher, or if there are no significant differences between the sections' median times.

Table 8.6: Difference test results for students' time spent in each RC section.

Module	Friedman test results & W effect size	AT – Algebra	Algebra - FC	AT - FC
A 2021	$\chi^2(2)=47.25$, $p<.001$, W=0.53	AT>Algebra, p=.097	Algebra>FC, p<.001	AT>FC, p<.001
B 2021	$\chi^2(2)=35.97$, $p<.001$, W=0.67	AT>Algebra, p=.254	Algebra>FC, p<.001	AT>FC, p<.001
C 2021	$\chi^2(2)=36.65$, $p<.001$, W=0.74	AT<Algebra, p<.001	Algebra>FC, p<.001	AT>FC, p=.061
D 2021	$\chi^2(2)=10.83$, $p=.006$, W=0.75	AT>Algebra, p=.002	Algebra>FC, p=.384	AT>FC, p=.108
E 2021	$\chi^2(2)=17.79$, $p<.001$, W=0.77	AT>Algebra, p<.001	Algebra>FC, p=.037	AT>FC, p=.097
A 2022	$\chi^2(2)=129.33$, $p<.001$, W=0.56	AT>Algebra, p<.001	Algebra>FC, p<.001	AT>FC, p<.001
B 2022	$\chi^2(2)=287.88$, $p<.001$, W=0.54	AT>Algebra, p<.001	Algebra>FC, p<.001	AT>FC, p<.001
C 2022	$\chi^2(2)=122.82$, $p<.001$, W=0.55	AT>Algebra, p=.174	Algebra>FC, p<.001	AT>FC, p<.001
D 2022	$\chi^2(2)=78.29$, $p<.001$, W=0.56	AT<Algebra, p<.001	Algebra>FC, p<.001	AT>FC, p=.595
E 2022	$\chi^2(2)=16.42$, $p<.001$, W=0.69	AT<Algebra, p=.001	Algebra>FC, p<.001	AT>FC, p=.373

The FC section was least used as students spent more time in the Algebra section and in the AT section. These differences were significant for all cohorts except D 2021 when comparing Algebra to FC, and significant for modules A and B in both years, and module C in 2022 when comparing AT to FC. Most students spent more time in the AT section of the RC than the Algebra section, this was significant for cohorts D 2021, E 2021, A 2022, and B 2022. However, cohorts C 2021, D 2022, and E 2022 spent significantly more time in the Algebra section than in the FC section. Students spending significantly less time in the FC section of the RC is in direct contrast to the quiz feedback provided to most students. Many students were recommended to engage with the FC section. Students spent more time in the AT section but comparatively few were recommended to engage with that section (Mullen and Cronin, n.d., Chapter 7). This contrast may be a result of students using the RC more before they received their quiz feedback than afterwards, but when students used the RC was unable to be measured. Nonetheless, MathsFit Quiz recommendations about RC sections and students' use of the sections did not align.

8.4.2.2 Videos versus Practice questions

Figure 8.5 compares students' engagement with the Refresher Course videos versus practice questions for RC users from the 2021 and 2022 modules, except for C 2021. Comparisons were considered by mean time difference (time spent on practice questions minus time spent on videos) across the whole RC. Positive values indicate more time was spent on practice questions, while negative values indicate more time was spent on videos. The green lines and asterisks within the graph indicate differences between the cohorts ($H(8)=277.49$, $p<.001$, $\varepsilon^2=0.18$, CI=0.14, 0.21). The asterisks below the horizontal axis labels indicate if the difference between videos and practice questions was significantly different to zero for that cohort, calculated by paired Wilcoxon tests.

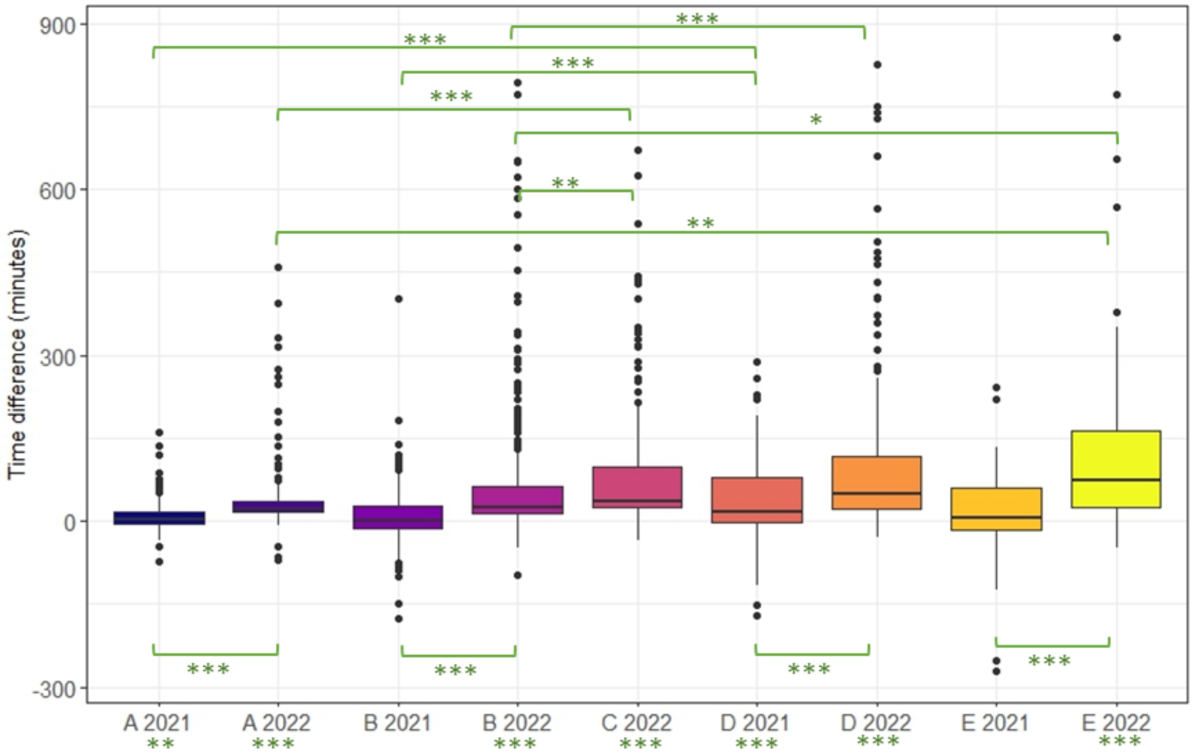

Figure 8.5: Difference between MathsFit participants' time spent watching videos and doing practice questions in the Refresher Course by year and module.

All cohorts except B 2021 and E 2021 spent significantly more time doing practice questions than watching videos. Each 2022 module had a greater difference between the time spent on videos and time answering practice questions than its 2021 counterpart. Comparing modules of the same year, the difference between practice questions and video use was significantly greater for module D compared to modules A and B in 2021. In 2022, module A had a significantly smaller difference than modules C and E, while module B had a significantly smaller difference than modules C, D, and E. Modules D and E, the engineering modules with higher prerequisites for students' previous mathematical learning, had an especially greater preference for practice questions in 2022. This might indicate that these students already knew the concepts covered in the videos and wished to practice applying the concepts through practice questions. Or perhaps they preferred the interactivity and feedback offered by the practice questions. The students from the five modules interacted with videos and practice questions differently. Comparing Figure 8.5 to Figure 8.3, it seems the additional time modules C, D, and E spent in the RC, compared to modules A and B, was spent doing practice questions. Despite the greater time spent on the practice questions, there was still time spent on the videos demonstrating that students will use both.

8.4.2.3 Demographic differences

Looking at differences in total time spent in the RC by demographic data, there were no significant differences in any of the modules when students were grouped by their previous grade. There was only one module, B 2022, with a difference based on students' "Curriculum Covered" answer ($H(2)=9.8$, $p=.022$, $\varepsilon^2=0.03$, CI=0.01, 0.07) with significant differences between those who chose "Covered" and "Not covered", and those who chose "Not covered" and "Unsure"—those who chose "Not covered" spent significantly more time in the RC. Females in B 2021, D 2021, and B 2022 spent more time in the RC than males ($H(1)=5.73$, $p=.045$, $\varepsilon^2=0.01$, CI=0.00, 0.04; $H(1)=11.86$, $p=.005$, $\varepsilon^2=0.04$, CI=0.01, 0.09; $H(1)=12.22$, $p<.001$, $\varepsilon^2=0.03$, CI=0.01, 0.07). There was no difference between males and females in the other modules. Similarly, only B 2021 and C 2022 had a significant difference between international and domestic students in time spent in the RC ($H(1)=8.61$, $p=.038$, $\varepsilon^2=0.01$, CI=0.00, 0.05; $H(1)=6.06$, $p=.040$; $\varepsilon^2=0.02$, CI=0.00, 0.08) with the international students spending more time in the RC in both modules B 2021 and C 2022. The other modules had no significant differences between international and domestic students for RC total time. Finally, grouping by student's previous examination revealed three modules with significant differences, as shown in Table 8.7. Sample sizes are presented with the differences for context.

Table 8.7: Differences in MathsFit cohorts' total time spent in the RC when grouped by previous examination system.

Module & Year	ANOVA or Kruskal-Wallis	Effect size (ε^2) & C.I.	Post hoc test	Differences
A 2021	$H(7)=23.58$, $p=.005$	$\varepsilon^2=0.07$, (0.03, 0.16)	Dunn	MSAP (*n*=4) > A-levels (*n*=1) MSAP (*n*=4) > IB (*n*=2) MSAP (*n*=4) > LC (*n*=294) Other (*n*=6) > LC (*n*=294) Other (*n*=6) > MSAP (*n*=4) MSAP (*n*=4) > QQI (*n*=25) MSAP (*n*=4) > SATs (*n*=2) MSAP (*n*=4) > UCD Access (*n*=1) QQI (*n*=25) < Other (*n*=6)
B 2022	$H(7)=18.34$, $p=.038$	$\varepsilon^2=0.04$, (0.02, 0.10)	Dunn	SATs (*n*=6) > LC (*n*=357) SATs (*n*=6) > Other (*n*=20) SATs (*n*=6) > QQI (*n*=15) SATs (*n*=6) > UCD Access (*n*=3)
D 2022	$H(4)=15.16$, $p=.014$	$\varepsilon^2=0.0525$, (0.03, 0.14)	Dunn	No significant differences once p-values were adjusted.

8.4.3 Maths Support Centre engagement

Students were advised to visit the MSC in their MathsFit feedback email which was triggered by their first quiz attempt if they scored a Bronze (less than 70% in 2020, less than 75% in 2021, and less than 62.5% in 2022, Mullen and Cronin (n.d., Chapter 7)) in one or more of the three quiz sections. Table 8.8 presents the number and percentage of participants per module and year that were advised to use the MSC. The notable differences between the 2021 and 2022 number of MSC visit recommendations per module are due in part to the change in Bronze medal thresholds, the number of students who had technical difficulties during their first quiz attempt in 2021, removal of the quiz time limit in 2022, and other design evolutions explained in Mullen and Cronin (n.d., Chapter 7).

Table 8.8: Number of students in each module and year who were advised to visit the MSC.

Module	2020	2021	2022	Total
A	88.14% (223)	98.51% (330)	60.34% (108)	86.18% (661)
B	59.02% (265)	95.41% (437)	41.89% (173)	66.29% (875)
C	NA	93.41% (241)	37.64% (99)	65.26% (340)
D	NA	87.03% (275)	28.21% (66)	62.00% (341)
E	NA	91.18% (62)	26.19% (11)	66.36% (73)
Total	69.52% (488)	93.73% (1,345)	40.41% (457)	70.07% (2,290)

Analysis of the MSC visit data related to MathsFit will consist of analysing each of the five modules' visit data over a number of years, and looking at two similar first-year modules, though for specialist mathematics students, for comparison, before the demographic differences in MSC use are presented. Note, all figures in the next two sections use singular years and these refer to the autumn semester of that year only. For example, 2016 denotes the autumn semester of the academic year 2016/17.

Figure 8.6 shows the percentage of students in each module who used the MSC in the years 2016 to 2022. The format of the MSC, in-person only, online only, or a hybrid of both is shown by the background shading, while the years of module participation in MathsFit are shown by triangular points instead of circular. Note, module E was created in 2019 so its MSC data similarly starts in 2019.

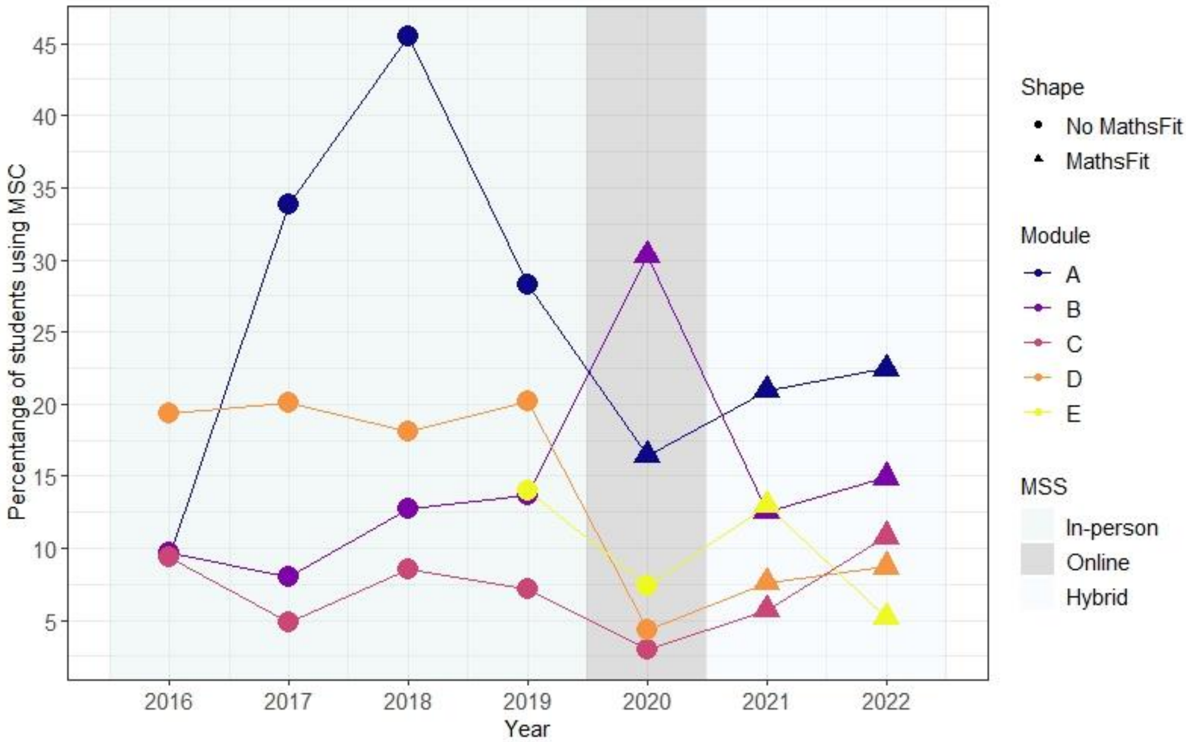

Figure 8.6: Percentage of students in the MathsFit modules who used the MSC in 2016–2022.

The percentage of students in modules A and B who used the MSC during 2020, when all university classes and services were online, points towards the success of MathsFit in informing and encouraging students' use of the MSC. The study groups, a part of the follow-up support that was only used by students in 2020, naturally increased MSC visits.

8.4.3.1 Module A

Figure 8.7 presents the student population of module A from 2016 to 2022 separated into four categories: the percentage of those who did not visit the MSC (dark blue), those who visited once (purple), students who visited two to four times (orange), and those who visited five or more times (yellow). The significant differences between years ($H(6)=146.53$, $p<.001$, $\varepsilon^2=0.06$, CI=0.05, 0.08) are shown in green with, as before, the number of asterisks indicating level of significance. As testing numerical data instead of categorical data provides stronger results, the differences tested were for students' number of MSC visits each year, not the category of visitor they belong to, as presented in Figure 8.7.

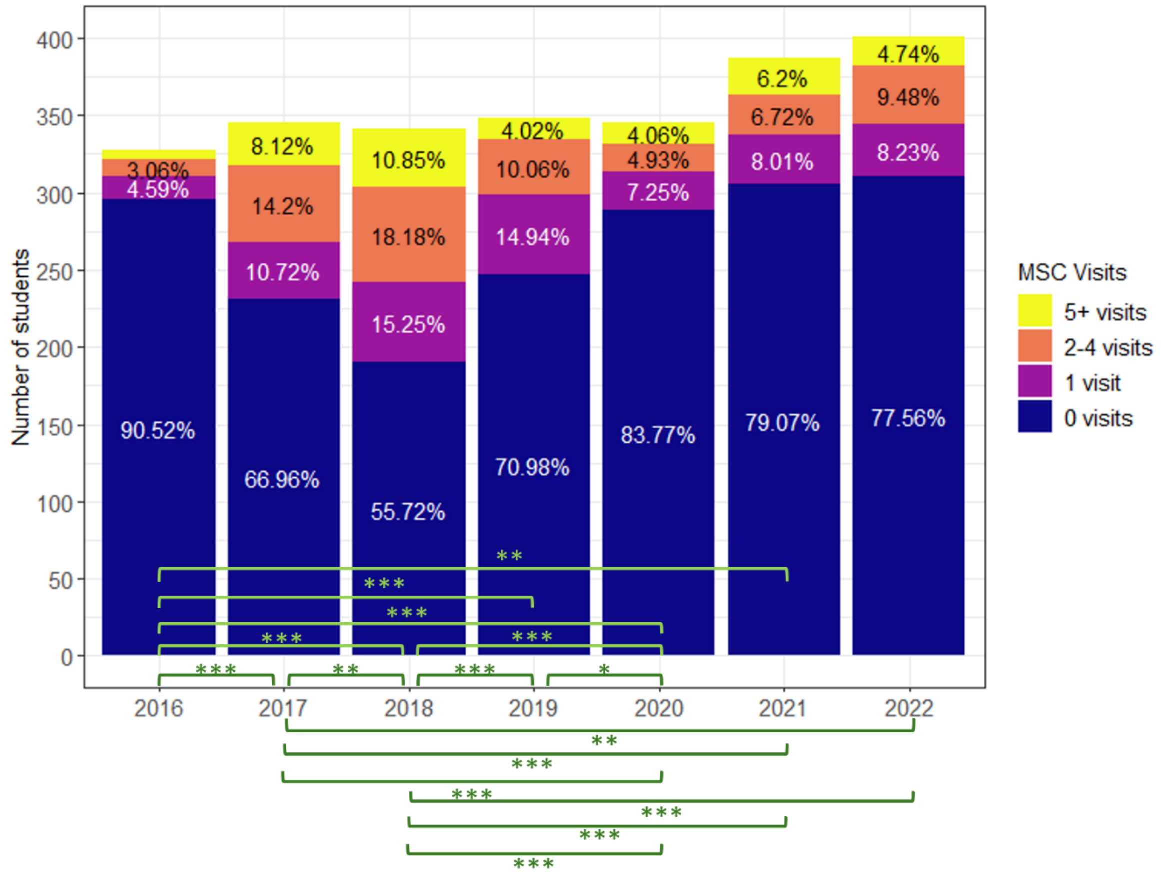

Figure 8.7: MSC visits by module A students 2016–2022.

Factors impacting module A during the years 2016 to 2022 include a change in lecturer from 2016 to 2017, and the move to online teaching, learning, and assessment due to COVID-19. The increase in visits from 2016–2018, followed by a decrease in 2019 could be explained by the change in lecturer. A lecturer who is new to a module may take some time to adapt how they wish to teach the module. This can affect support use. The decrease from 2019 to 2020 is presumably due to the pandemic, and the increase in visits during the MathsFit years of 2020–2022 is most likely a combination of a move to hybrid or back to in-person support and MathsFit.

8.4.3.2 Module B

Figure 8.8 presents the module B MSC visit data in the same style as the previous figure, though the first semester of the 2015/16 academic year is also included. Similar to module A, significant differences between years were found ($H(7)=139.00$, $p<.001$, $\varepsilon^2=0.04$, CI=0.02, 0.05). Module B was involved in previous mathematical education research (Howard et al., 2018; Howard et al., 2019) and had a number of supports other than the MSC in place, including tutorials, and a module specific two-hour drop-in session held weekly in a large classroom. These supports were on students' timetables. There were both in-person lectures and videos available to students. Thus, the relatively low engagement within the MSC from 2015 to 2019 is not surprising. The large increase in visits in 2020 is notable. It cannot be attributed to MathsFit alone. As a consequence of the move to online teaching and learning, the drop-in session became an interactive lecture, the in-person lectures were cancelled, and students were directed to the videos. The tutorials remained, though in an online format, and an online discussion forum was opened for students. Assessment practices also changed. Advertisement of the MSC by the lecturer was a more regular occurrence in 2020. However, MathsFit contributed to the increase, with measures like the study groups, as discussed, in place. The return to more typical patterns of MSC visits in 2021 and 2022 aligns with the return to in-person module teaching and lack of engagement with study groups. The continuation of MathsFit contributes to the slightly higher number of visitors in 2021 and 2022 than pre-2020.

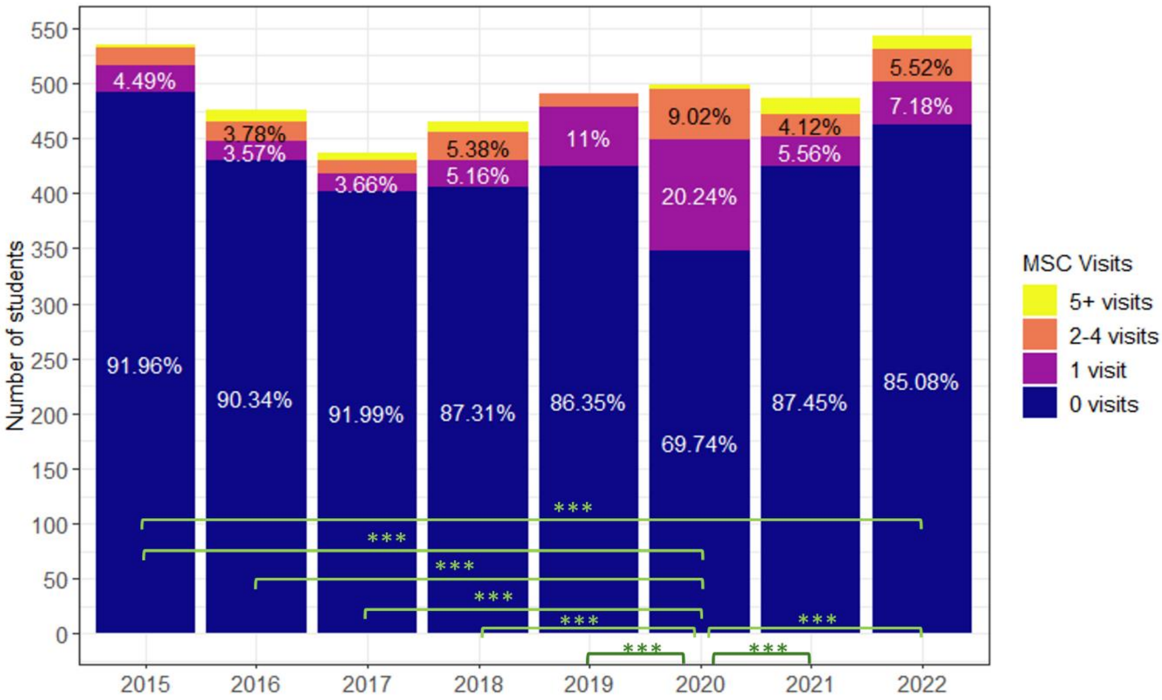

Figure 8.8: MSC visits by module B students 2015–2022.

There have been a number of lecturer changes during 2015–2022, with combinations of four different lecturers involved in teaching module B (sometimes two lecturers were assigned to this large module). However, one lecturer has taught the module from 2018 and was the sole lecturer from 2019 onwards. The percentage of module B students using the MSC during these years was above 10%.

8.4.3.3 Module C

Figure 8.9 presents the MSC visit data for module C between 2016 and 2022 with the one significant difference found, between 2020 and 2022 MSC visits ($H(6)=21.14$, $p=.007$, $\varepsilon^2=0.01$, CI=0.01, 0.02).

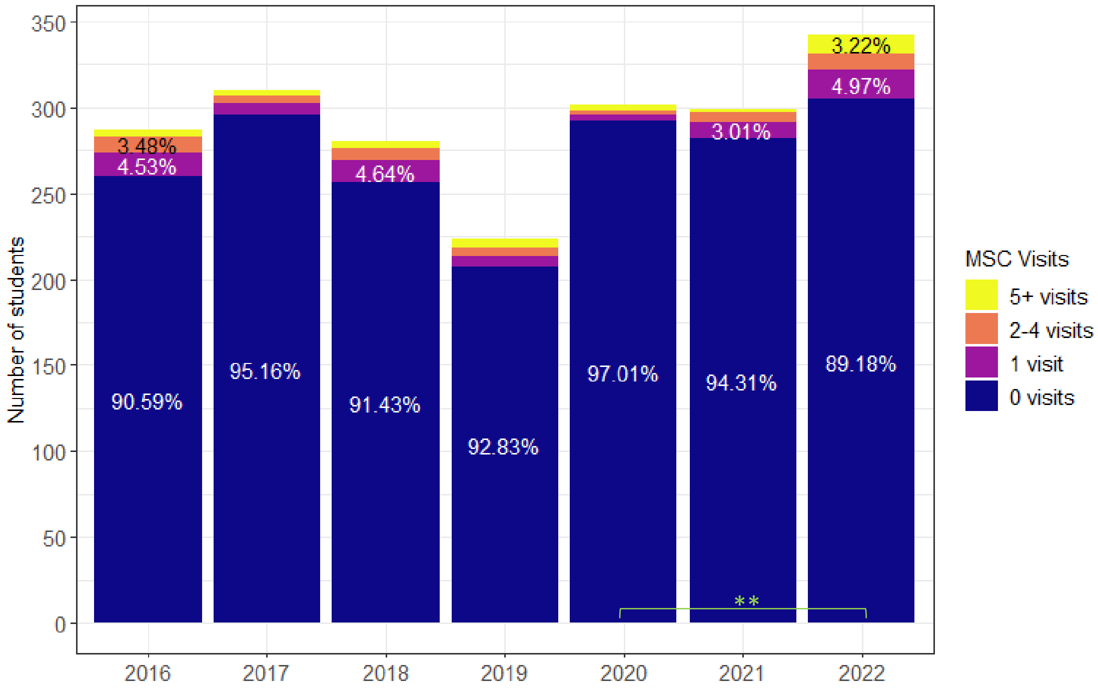

Figure 8.9: MSC visits by module C students 2016–2022.

One of the key factors to understand Module C's MSC visit patterns is that this module was offered in the spring semester until, in 2019, it was moved to the autumn semester. This may explain the low number of visitors pre-2019 as visits are usually lower in the spring semester (potentially as first-years are more adjusted to university, and in particular university mathematics learning). The module it swapped semesters with, Linear Algebra for Science, had a much higher percentage of visitors when scheduled in the autumn semester. Another factor is that the content in module C overlaps considerably with the Higher Level Leaving Certificate mathematics curriculum. As most students, recalling the demographical information where over 75% of module C students sat the LC in 2021 and 2022, have seen the content before, it is reasonable to suggest that they need little or no additional support with it.

The effect of the move online is clear in Figure 8.9 with the lowest number of visitors in 2020, and the increase in visitors in 2021 is a return to something approaching normal. The increase in 2022 is the highest amount of visitors in the time period shown. This may be due to MathsFit. Only one change in lecturer has occurred during the years shown for module C, and that was in 2018. This does not seem to have impacted MSC visits.

8.4.3.4 Module D

Figure 8.10 shows module D's MSC visit data from 2015 to 2022. Like modules A and B, module D had significant differences between years ($H(7)=208.49$, $p<.001$, $\varepsilon^2=0.08$, CI=0.06, 0.11). For a module that has many significant differences in how students used the MSC, there are not many teaching and learning factors that have changed for the module. Module D has had two lecturers during the years shown, one from 2015–2017 and the other from 2018 onwards. The change in lecturer aligns with a reduction in the percentage of students visiting five or more times, but the percentages of non-visitors remained similar until 2020. The clear reduction in MSC use in 2020–2023 compared to the previous years is an interesting development. The reduction in 2020 could be attributed to the move online but the lack of resurgence in visits, especially with MathsFit running in 2021 and 2022, is more difficult to understand compared with the other modules.

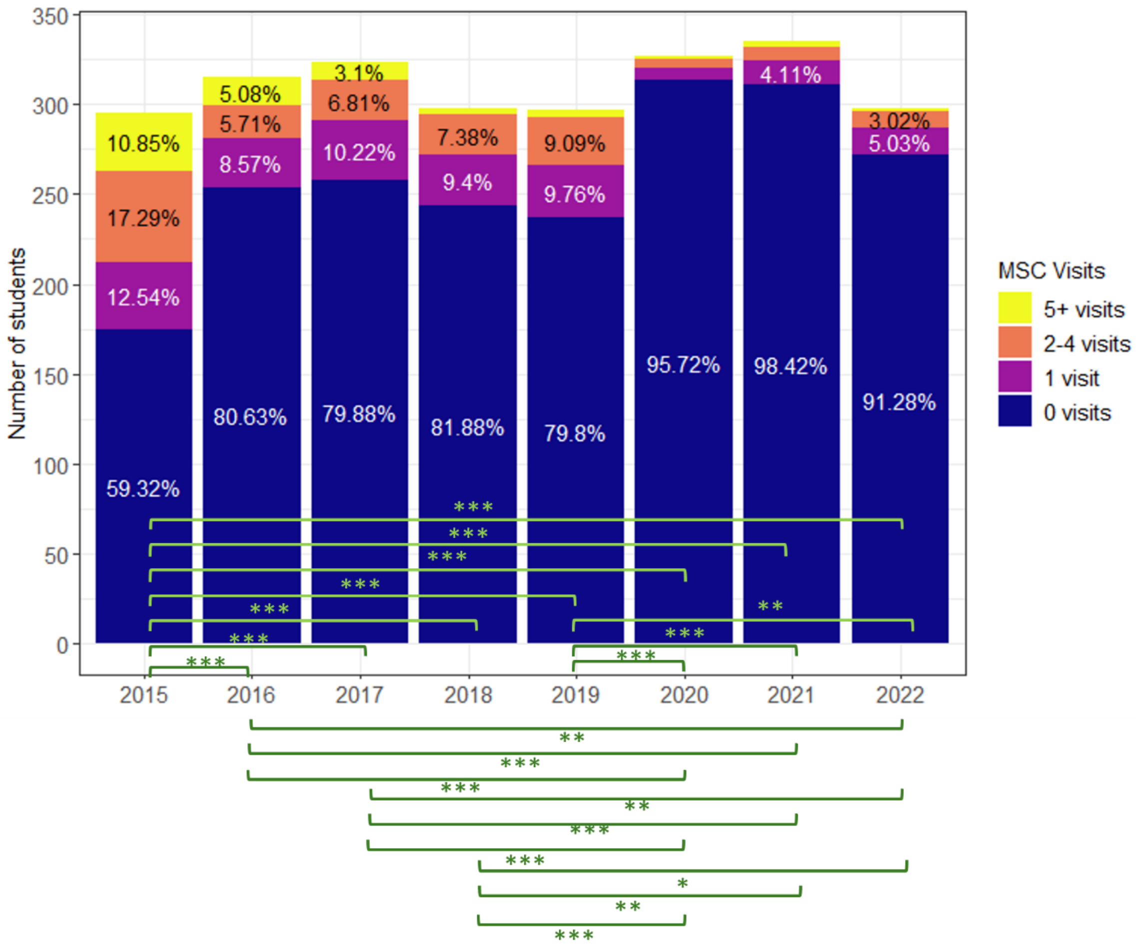

Figure 8.10: MSC visits by module D students 2015–2022.

8.4.3.5 Module E

Figure 8.11 shows the four years of MSC data for module E which has only been available for four years. There were no significant differences between these years' number of MSC visits ($H(3)=3.29$, $p=.349$, $\varepsilon^2=0.02$, CI=0.03, 0.07).

Module E students attend the same lectures (with the same lecturer) as module D students, have tutorials as a group, and have an additional lecture that module D students do not attend. The increase in visitors in 2021 might suggest that MathsFit had an effect on module E students' MSC visits. While visits decreased in 2022, less students in module E were advised to visit the MSC based on their MathsFit results (see Figure 7.1).

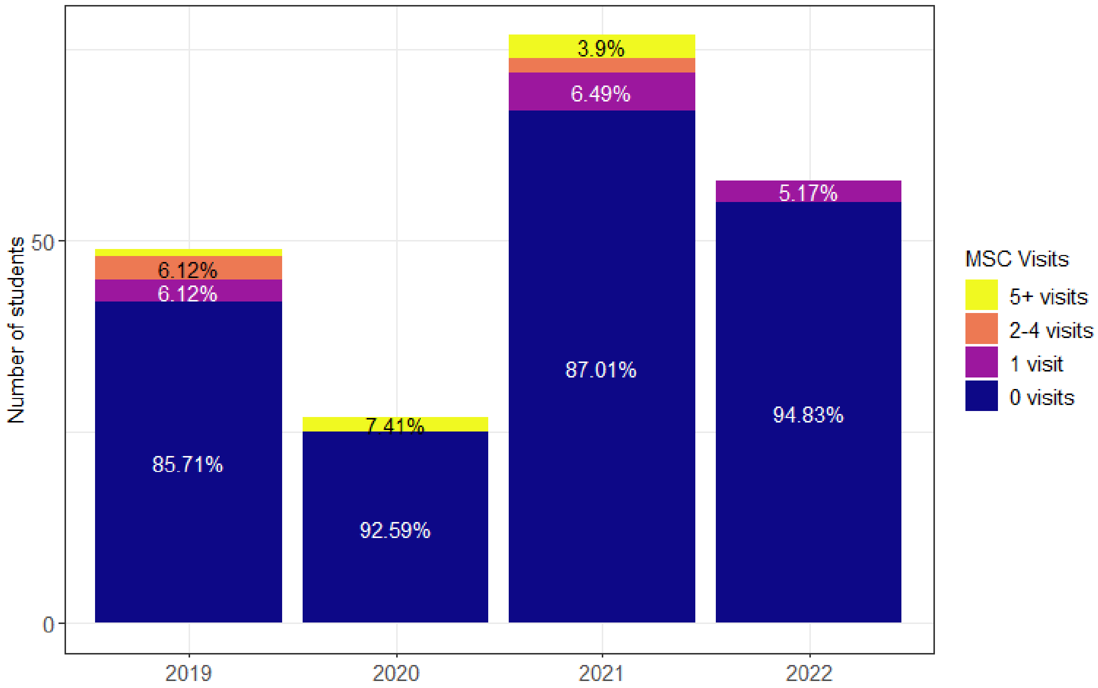

Figure 8.11: MSC visits by module E students 2019–2022.

8.4.3.6 Comparison to similar modules

Due to the large and varying number of modules (100+ per annum) that make use of the MSC, a calculation of the percentage of students who use the MSC from the total student population to whom the MSC is available was not practical. While visit and visitor counts are available for all modules who use the MSC, the changing population of each module involved would be needed to ensure percentage increases and decreases were not impacted by module population changes. As the previous figures have shown, module population change is frequent. Instead, two other first-year modules will be used to compare with MathsFit modules' MSC use.

Visit data for two large first-year first-semester modules, called BA and MP, are presented in Figures 8.12 and 8.13 respectively. BA is the first calculus module completed by students who are studying mathematics through the Bachelor of Arts programme during the autumn semester and MP is the advanced counterpart to Module C, being the calculus module for students who want to study mathematics or physics, and related subjects through the Bachelor of Science programme. MP therefore has the same CAO points requirement as module C, though a H3 LC mathematics grade is recommended. BA points were 310, 381, and 400 for 2020, 2021, and 2022 respectively, and at least a H4 in LC mathematics is recommended. These modules were not targeted in MathsFit as both student cohorts chose to study a mathematics-based degree rather than the five non-specialist modules involved in MathsFit. The BA students chose mathematics as one of their three first-year subjects to study (subsequently they select two subjects for their major in second and third year). MP students chose to do MP over module C. MP is a core module for students planning to study mathematics, physics or mathematics education but students planning to study other science subjects may choose MP instead of module C.

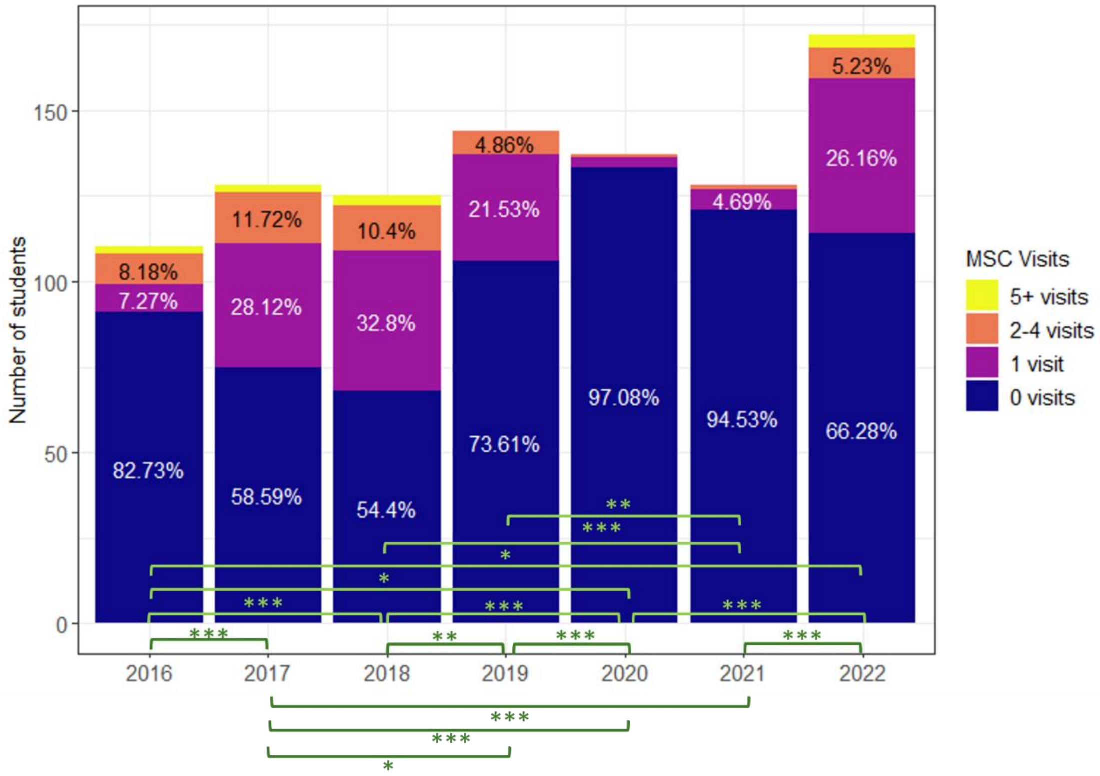

Figure 8.12: MSC visits by BA students 2016–2022.

BA MSC visits per year, presented in Figure 8.12, were also tested for differences and significant change across the years was found ($H(6)=116.32$, $p<0.001$, $\varepsilon^2=0.12$, CI=0.10, 0.17). BA visit patterns show that between 15 and 45 percent of students used the MSC before the move to online support, when students rarely visited. This reduction in visits continued in 2021. The increase in visits in 2022, though not to the same levels seen in 2017 and 2018, may signal a return to normal. It must be noted that the lead researcher was requested by the lecturer to contact BA students in 2022 in a style similar to the MathsFit feedback emails, based on students' midterm results which, as a whole, were poor. The same lecturer has been teaching this module for all years presented. Thus a notable change in teaching and assessment has not occurred (other than that imposed by the challenges of being online) and therefore MSC visits have been unaffected by a change in lecturer. Differences identified here are similar to those of module A and D, which also had higher percentages of students visiting pre-2020. The change in MSC engagement in the 2020s is clear.

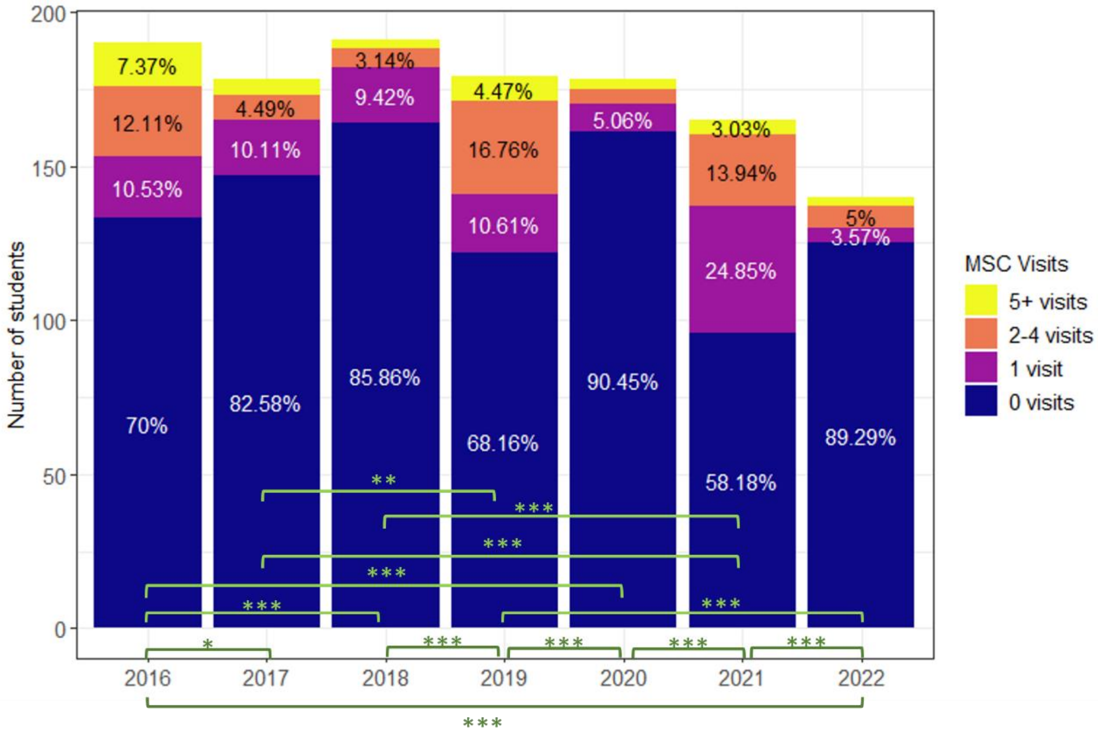

Figure 8.13: MSC visits by MP students 2016–2022.

MP MSC visits also had significant differences in number of visits between years (H(6)=87.79, p<.001., ε^2=0.11, CI=0.08, 0.15). Like module C, MP was scheduled in the spring semester until 2019 when it was moved to the autumn semester and there were significantly more visits in 2019. The MP module, like BA, shows that at least 14% of its students visited the MSC every year pre-2020. Visits reduced in 2020 but not to the same extent as modules C, D and E. There was a significant resurgence of visits in 2021 when a new high of 42% of students visited, followed by a significant reduction in 2022 when numbers fell to similar levels as 2020. There have been four different lecturers and assessment regimens for this module over these seven years which may account for the significant variability of student visits. Different teaching styles and assessment foci can impact student use of the MSC.

Figure 8.14 shows the BA and MP modules' visit trends in isolation, while Figure 8.15 presents the five MathsFit modules and the two comparison modules BA and MP. From Figure 8.14, the 2020 decrease and the variability in the percentage of students visiting is clear. Figure 8.15 highlights the similarities between module A and the BA module pre-MathsFit, and module MP's lack of similarity to all other modules. Comparing the visit trend of modules A and BA suggests the positive effect MathsFit had on module A visits during 2020 as module BA demonstrates a lower percentage of visitors. The variance in module MP visit trends may be attributed to the change in lecturers as previously discussed. However it must be considered that these students have most likely chosen to study mathematics or physics for their degree, and therefore may use the MSC differently as a result.

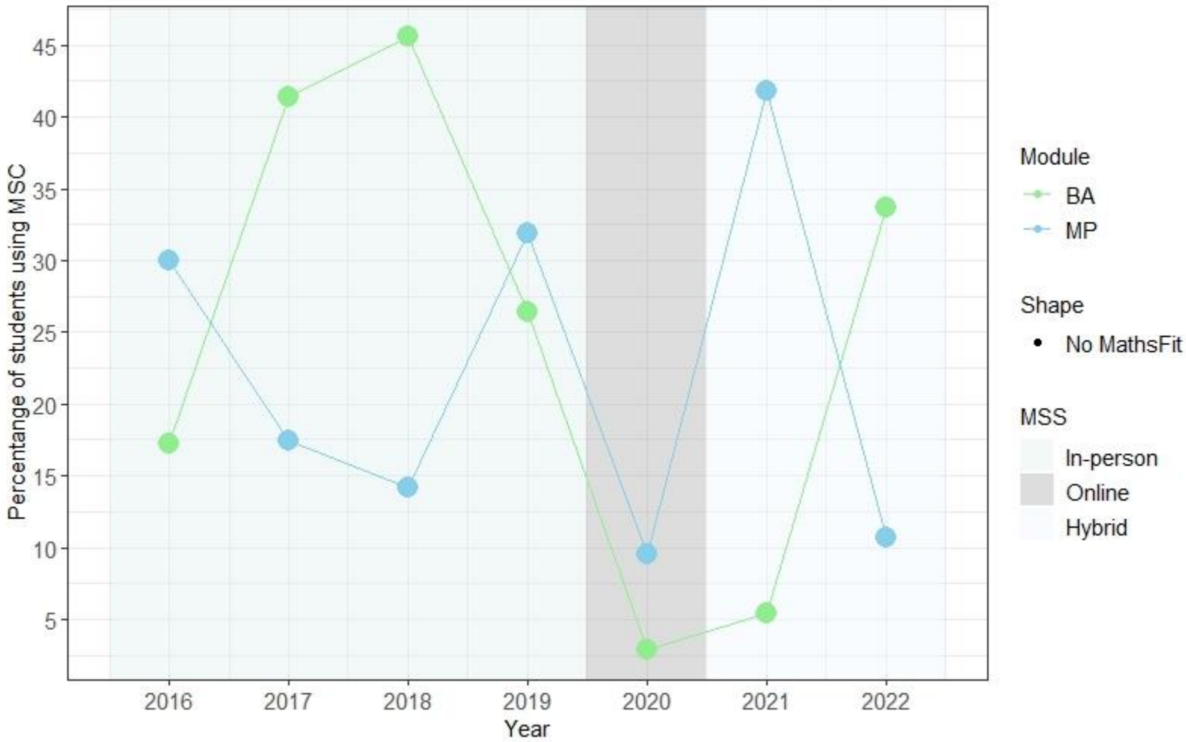

Figure 8.14: Percentage of BA and MP students who used the MSC 2016–2022.

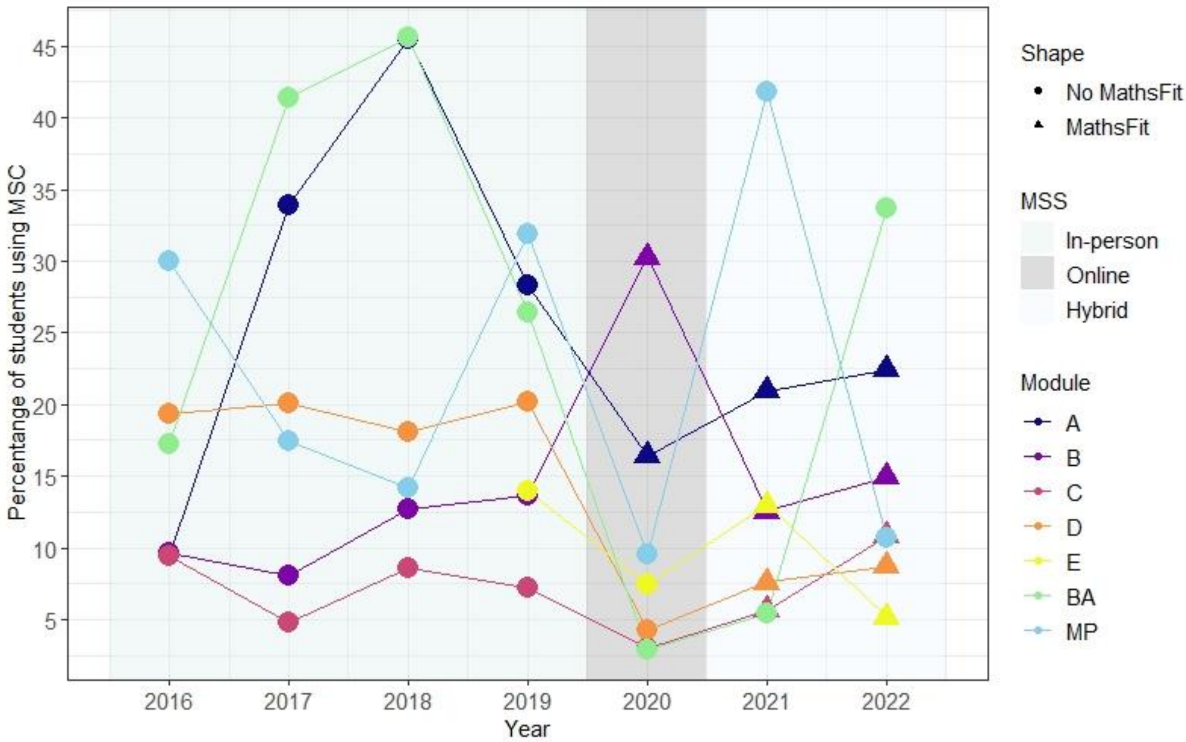

Figure 8.15: Percentage of MathsFit modules, BA and MP students who used the MSC 2016–2022.

8.4.3.7 Demographic and Previous Education differences

Kruskal-Wallis tests and Dunn post hoc tests revealed differences in the number of MSC visits by the MathsFit modules students based on gender, international status, degree, curriculum coverage, previous grade, and previous examination. These are summarised in Table 8.7.

Table 8.7: Differences in MSC visits when grouped by demographic and previous education factors.

Variable	Module & Year	Kruskal-Wallis result	Effect size (ε^2) & C.I.	Differences
Gender	B 2020	H(1)=16.03, p<.001	ε^2=0.04, (0.01, 0.08)	Female>Male
Gender	A 2021	H(1)=10.55, p=.005	ε^2=0.03, (0.01, 0.07)	Female>Male
Gender	B 2021	H(1)=17.68, p<.001	ε^2=0.04, (0.01, 0.08)	Female>Male
Gender	E 2021	H(1)=8.31, p=.017	ε^2=0.13, (0.02, 0.28)	Female>Male
International status	B 2021	H(1)=8.61, p=.011	ε^2=0.02, (0.00, 0.07)	International > Domestic
International status	B 2022	H(1)=7.05, p=.025	ε^2=0.02, (0.00, 0.06)	International > Domestic
Curriculum	D 2021	H(2)=9.39, p=.0269	ε^2=0.04, (0.02, 0.09)	Not covered > Covered
Curriculum	B 2022	H(2)=10.15, p=.0194	ε^2=0.32, (0.01, 0.08)	Not covered > Covered Not covered > Unsure
Previous Grade	B 2020	H(7)=28.96, p<.001	ε^2=0.06, (0.03, 0.13)	4>6, 4>7, 4>8, 4>9, 5>9
Previous Grade	B 2021	H(7)=55.23, p<.001	ε^2=0.12, (0.06, 0.23)	5>9, 2>9, 5>8, 2>8, 5>7
Previous Grade	D 2021	H(4)=13.65, p=.0269	ε^2=0.04, (0.01, 0.17)	No significant differences once p-values were adjusted.
Previous Grade	B 2022	H(7)=40.74, p<.001	ε^2=0.10, (0.05, 0.21)	3>9, 1>9, 4>8, 3>8, 1>8, 3>6, 3>7
Previous Grade	C 2022	H(7)=27.71, p<.001	ε^2=0.11, (0.07, 0.22)	5>9, 7>9
Previous Grade	D 2022	H(4)=19.67, p=.0042	ε^2=0.08, (0.02, 0.23)	6>9, 8>9
Previous Exam	A 2020	H(3)=12.67, p=.0167	ε^2=0.05, (0.01, 0.17)	QQI > LC
Previous Exam	A 2021	H(7)=18.13, p=.0320	ε^2=0.05, (0.02, 0.11)	MSAP > LC MSAP > Other
Previous Exam	B 2021	H(6)=32.83, p<.001	ε^2=0.08, (0.05, 0.13)	QQI > LC
Previous Exam	C 2021	H(6)=31.6, p<.001	ε^2=0.06, (0.03, 0.13)	UCD Access > A-levels UCD Access > IB UCD Access > LC UCD Access > Other UCD Access > QQI UCD Access > SATs
Previous Exam	A 2022	H(4)=14.59, p=.019	ε^2=0.04, (0.01, 0.11)	No significant differences found once p-values adjusted
Previous Exam	B 2022	H(7)=19.05, p=.025	ε^2=0.05, (0.02, 0.13)	No significant differences found once p-values adjusted
Previous Exam	C 2022	H(8)=23.03, p=.011	ε^2=0.15, (0.09, 0.25)	QQI > LC

8.5 Discussion

MathsFit was designed and implemented to alert UCD non-specialist mathematics students to their possible need for support early in their first semester of university. MathsFit was especially pertinent at the time of implementation with concerns about students' lessened mathematical preparation and reduced first semester in university due to the pandemic (Mullen & Cronin, n.d., Chapter 7)). Another form of support, the Refresher Course, an online suite of videos and interactive practice questions, was created as part of MathsFit. Student use of both this new support and the existing support, the MSC at UCD, was examined in this paper. Overall, relatively high engagement with the RC was recorded while MSC use was lower with only a small percentage of students visiting. The difference between the number of students who were recommended to use the MSC, and in some years the RC, and those who actually used the support was stark, similar to other reports (Burke et al., 2012; Sheridan, 2013).

RC use was more easily influenced due to MathsFit design decisions. Table 8.4 indicates that the decision to make the RC accessible through Brightspace both before and after students attempted the quiz increased use of the RC - the percentage of module A and module B students who used it in 2021 doubled compared to 2020. The strategy to instruct the students to use the RC in the MathsFit tutorial in 2022 meant that nearly all students accessed the RC, explaining the significant difference in time spent in the RC between 2021 and 2022.

The significant differences between the total time spent in the RC by students from modules A and B compared to modules C, D, and E in both 2021 and 2022 is an interesting report on these students' behaviour. Module A students spending less time in the RC was perhaps to be expected as there was no academic credit incentive for these students to participate in MathsFit and this was reflected with lesser engagement in most aspects of MathsFit. The other four modules offered up to 3% of their continuous assessment based on their MathsFit quiz result. Module B students spending less time in the RC than students from the other modules was unanticipated as they were rewarded for their MathsFit quiz score (though it was part of a group of nine continuous assessment assignments from which the best seven scores were taken for the final continuous assessment result). A possible explanation is that their continuous assessment schedule overlapped with MathsFit timing more than for students from the other modules. Timing was a concern for students who were overwhelmed by all they had to do in the first weeks of the semester (Mullen & Cronin, n.d., Chapter 7). The timing of students' first tutorial may also have played a role in how much time students spent in the RC. Anecdotal evidence suggests that students whose tutorial occurred later in the week explored more of the RC in anticipation of their MathsFit tutorial. All module B tutorials were scheduled on Tuesday, whereas all module E tutorials took place on Friday which may explain, in part, the comparatively higher engagement by module E students.

Further analysis of students' time in the RC revealed that they spent significantly less time in the Functions and Calculus (FC) section, which was surprising as this was found to be the lowest scoring quiz section (Mullen & Cronin, n.d, Chapter 7). The RC was organised so that students saw Arithmetic and Trigonometry (AT) materials first, followed by Algebra, then FC to follow the order of the quiz sections. Perhaps, as most students spent more time in the AT section than the Algebra section, they worked on what they saw first and did not persevere or return to later sections. Based on the medal results, most students' feedback emails suggested further engagement with the Algebra and FC sections but this does not seem to be reflected in the time per section of RC accessed. Students' use of the RC videos compared with the RC practice questions suggest preference for practice questions by most students. Design comes into question here too. In 2022, when a more marked preference for practice questions was noted, the questions and videos were separate with the videos in Brightspace and the questions in Bolster Academy. It would have been easier for students to move between questions than to move between questions and videos. Whereas in 2021 the videos and questions were together in Brightspace and use was more even. How students used the RC, and will use the RC, is of great interest. Analysis linking quiz question results and individual RC video/question visits could provide further information in this vein. However, the limiting factor of not knowing exactly when students visited the RC remains. Further design work in how best to present videos and practice questions together and in which order alongside data collection advancements would aid both students and research in this area.

Comparing the use of the MSC prior to September 2020, i.e. pre-MathsFit, with MSC use during MathsFit was not without issues. The beginning of exclusively online MSS (due to the pandemic) and MathsFit are close timepoints and their effects are difficult to disentangle. Multiple other factors that affect students' use of MSS (e.g., Gokhool, 2023) exist, only some of which were captured in MathsFit data collection. Therefore, any conclusions drawn about the effect MathsFit had on MSC attendance will be correlational and not causation. The number of student visits to the MSC declined considerably in 2020 (a global trend (Gilbert et al., 2021; Hodds, 2020; Mullen et al., 2021a) and have yet to recover to pre-pandemic levels. Thus, the (mostly) significant reduction in the percentage of students from the MathsFit modules who visited during 2020–2022, is reflective of the lower university-wide MSC attendance. The significantly higher number of module B student MSC visits during 2020 may be the result of MathsFit, particularly the study groups initiative, but support within the module in terms of tutorials and so forth, also changed considerably due to the online learning format imposed in 2020.

Visit data from modules BA and MP allow comparisons of the MathsFit modules visit data to two first-year modules that were not involved in MathsFit. Students in those two modules only learned about the MSC through advertisements by lecturers and tutors. Results from surveys and interviews, presented in Mullen and Cronin (n.d., Chapter 7), indicate that MathsFit raised participants' awareness and use of the MSC. The difference in the percentage of students who visited the MSC from the BA and MP modules compared to the MathsFit modules agrees with that result. Future research into the distribution of student visits to the MSC throughout the semester and what MSC tutor feedback comments indicate about their use of the MSC may lead to further results about the impact MathsFit had on MSC use. This would allow identification of students who visited in relation to MathsFit topics versus those who visited with module content issues, creating a count of exactly how many students went to the MSC based on their feedback email prompt. Analysis of tutor feedback from visits about module content could determine if students had underlying issues with previous mathematical content that could have been or were resolved through MathsFit. Evidence from tutors indicates that most students' module content issues stem from a lack of or misunderstanding of required prior mathematical concepts (Curley, 2019).

Visit data for students who used the MSC during 2020–2022 suggests that there were many irregular visitors, with not many students visiting more than four times. The slight exception to this is students from module A where 4-6% of students visited five or more times. Previous analysis of the impact of the MSC on students' mathematical achievement (Mullen et al., 2021b) suggests that students who visited more gained greater benefit from the MSC. Jacob and Ní Fhloinn (2019), in their regression model, also found more MSC visits significantly increased students' odds of passing their mathematics module. Thus, the lack of regular visitors found is concerning.

Similar to findings from Gokhool (2023) and O'Sullivan et al. (2014), females in modules A, B and E in 2021, and in module B in 2020 made significantly more MSC visits than their male counterparts. Females in modules B and D in 2021, and B in 2022 also spent significantly more time in the RC. International students in module B in 2021 used both the MSC and RC significantly more while those in module B in 2022 used only the MSC significantly more than domestic students. Gokhool (2023) found similar higher engagement with MSS by international students. In comparison, in module C in 2022 the domestic students used the RC less than their international counterparts.

Students in cohorts B 2020, B 2021, B 2022, C 2022, D 2021, and D 2022 who had achieved lower mathematics grades in their pre-university mathematics examinations and those in cohorts D 2021 and B 2022 who knew they had not covered their entire pre-university mathematics curriculum, made a particular effort to attend the MSC. There was also increased MSC use from QQI and mature students (MSAP) in cohorts A 2020, A 2021, A 2022, B 2021, B 2022, C 2021, and C 2022. However, these trends of increased support use were not reflected in RC use except for students in B 2022 who had not covered their full pre-university mathematics curriculum, and mature and QQI students in module A in 2021. RC and MSC data were gathered across different time periods, the RC was available for approximately four weeks while the MSC was open throughout the semester. Perhaps the time restriction on the RC meant student use was even across groups or students preferred the type of support available in the MSC. Students in module B in 2022 who had taken SATs, on the other hand, spent more time in the RC than many of their classmates from different examination systems, but spent similar amounts of time in the MSC as their classmates.

Overall, the level of support uptake prompted by MathsFit was mixed. The new resource of the RC was used by many students, especially when they were given greater access to it (i.e. before and after the MathsFit quiz) and time to use it (i.e. their first tutorial). On the other hand, not as much MSC engagement occurred as was expected. This has to be put in the context of MSC use overall being low during the years of MathsFit analysed here due to the COVID-19 pandemic. However, comparing the number of students who were advised to use the MSC with the number who did use the MSC indicates that MathsFit did not work as anticipated in terms of prompting MSC use. Perhaps the RC was the support that MathsFit participants needed, or at least wanted, instead of the MSC, or students felt they did not need the support. Either way, this paper records a significant shift in students' MSC engagement. How students engage with support has changed and more research is needed to examine why and what impact this shift in engagement has had.

8.6 Conclusion

The results of this paper point to a number of concerns for the future provision of mathematics and statistics support. MSC visits, while increasing slowly post-pandemic, are still not at their previous levels. MathsFit alerted students to the availability of support, however, most students did not visit the MSC when prompted to and high uptake of the RC only occurred in 2022 when students were given specific time to use it – before their first quiz attempt. If MathsFit is evaluated as a programme to increase support use, its impact has been disappointing. Is this due to the programme's design or merely a consequence of post-pandemic disruption and the changed nature of student academic engagement more generally? MathsFit attempted to address the longstanding MSS research question of how to engage the non-engagers, the students who need MSS most. This paper indicates an answer has not yet been found with the group of non-engagers, at least at UCD, now larger than ever.

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9 Evaluating student support engagement: The impact of MathsFit, a student diagnostic and support programme

Abstract

MathsFit is a diagnostic and support programme for first-year non-specialist mathematics students that commenced in September 2020. Student participants receive personalised support recommendations based on their diagnostic quiz results, with the aim of encouraging early support use. Previous evaluation of mathematics and statistics support has found that support engagement can significantly improve students' mathematics and statistics results, especially those who visit frequently. In this paper, the supports offered by the MathsFit programme will be evaluated with respect to students' mathematics module results. Three years of MathsFit participants, from 2020/21–2022/23, involving 2,889 students from five modules are studied. Logistic regression is used to examine how students' MathsFit Quiz results, demographics, and support use impact whether students passed or failed their mathematics module. While students' MathsFit Quiz results and some demographic information were predictive of students' passing, mathematics support use was not found to be statistically significant. This unexpected outcome will be discussed with reference to the changing nature of mathematics and statistics support during the study period coupled with changes to higher education teaching, learning and assessment due to pandemic restrictions.

9.1 Introduction

MathsFit seeks to support first-year non-specialist mathematics students in their transition to university mathematics through the provision of carefully designed diagnostic tests which trigger personalised support suggestions (Mullen & Cronin, n.d.a). It is one component of the service offered by the Maths Support Centre (MSC) at University College Dublin, aiming to alert students to available support. As well as recommending an MSC visit to students who need it, MathsFit also offers a Refresher Course, an online curated selection of videos and practice questions aligned with the MathsFit Quiz mathematics topics. MathsFit participants include students from four degree programmes: Agriculture and Food Science, Business, Science, and Engineering, with five mathematics modules of students involved in the programme, labelled modules A, B, C, D, and E. This paper examines students' success (whether they passed or failed their respective module) in these mathematics modules in 2020, 2021, and 2022, the first three years MathsFit was conducted. Demographical (gender, international status, previous educational system), prior mathematics results, MathsFit Quiz performance, support use, and module attainment data were gathered from 2,889 participants during 2020-2022. This information will be analysed via logistic regression to answer the research questions:

1. Does students' engagement and attainment in MathsFit, particularly their use of the MSC and Refresher Course, affect their success in their mathematics module?
2. What other demographic or previous education factors have a significant effect on students' mathematics module success?

This evaluation of the impact of support use on students' mathematics module success, and investigation into the relationship between students' MathsFit Quiz results, demographics and their module success was conducted with support improvement at its centre. While the mathematics module assessment practices play a key role in these students' experiences, the support they interact with is the variable of interest here. Therefore, the interaction between students' demographics, previous education and module assessment results are of particular interest in ascertaining whether particular groups of students have a greater need of support. The impact of the support offered to them must be assessed to ensure that it is effective and improved as necessary.

9.2 Literature Review

Mathematics and statistics support (MSS) is the provision of additional extra-curricular support in mathematics and statistics to students in higher education. Recent literature reviews (Lawson et al., 2020; Mullen et al., 2024) show its establishment in the UK, Ireland, Australia, the USA and Germany, and point to its positive impact on students in terms of increased academic grades, improved mathematical confidence and greater retention. It was first established to aid students who were mathematically underprepared for higher education, an issue identified as the "mathematics problem" (Hawkes & Savage, 2000; Lawson et al., 2020). The identification of the mathematics problem in Ireland can be traced back to diagnostic test results from the University of Limerick over ten years that showed decreasing student performance (Gill et al., 2010; Hourigan & O'Donoghue, 2007). MSS, in the form of mathematics support centres (MSC) in Ireland, was put in place to aid these struggling students, whether identified through diagnostic tests or otherwise, and has since grown as an active research area focused on ensuring student success through support provision.

A key first step in evaluating a mathematics diagnostic and support programme such as MathsFit is identifying the purpose(s) of the programme in order to define the bounds of the evaluation. Drawing on literature from the UK, USA, Australia, Ireland, and Malaysia; Rylands and Shearman (2022) identified seven purposes of diagnostic testing. These were: predicting performance; identifying at-risk students, aiming to provide assistance; enabling students and/or staff decisions on the correct subject level for each student; requiring students to reach a set level of skills to progress; informing teaching staff about students' knowledge levels; informing students about their knowledge gaps; and informing non-mathematicians and decision makers about students' level of mathematical knowledge. These purposes overlap with the uses found by Gillard et al. (2010): informing students and tutors of any gaps in knowledge; comparing results of incoming students with previous years; identifying and targeting students in need of MSS; and guiding the development of additional support resources. These uses are based on the responses of 12 British universities to an email survey. It targeted 38 universities, 20 replied and 12 of those had diagnostic testing programmes. Both lists of purposes can be separated into information for university staff (including module lecturers, MSS staff, administrators, etc.) and information for students.

Information for staff—predicting performance (this is also informative for students), students' mathematics knowledge levels (particularly those "at-risk"), comparison of students between years, and guiding MSS resources may be obtained through diagnostic testing, especially long-standing programmes. Examples of such programmes include Coventry University, England (Lawson, 2003; Hodds et al., 2021; Hodds, 2021; Hodds, 2023) and the University of Limerick, Ireland (Faulkner et al., 2011; Fitzmaurice et al., 2021) where diagnostic testing has been in operation since 1991 and 1997 respectively. Comparing student diagnostic test results across years created valuable insights on reduction (Faulkner et al., 2011; Fitzmaurice et al., 2021; Lawson, 2003) and increase (Hodds et al., 2021) in students' mathematical competencies as well as indicating the impact of the pandemic on students' mathematical learning (Hodds, 2021; Hodds, 2023). This type of information is helpful in assisting staff to plan the pacing of lectures, volume of content to cover, and the amount of support to be offered. The results of the Swiss diagnostic test described in Akveld and Kinnear (2023) prompted the creation of a bridging course. Turner (2008) described an American initiative with a competency test that required students who failed three times to attend a support class that met twice weekly in addition to the regular schedule of Calculus I. This competency test was administered in September after a diagnostic test was taken in May that determined which, if any, summer MSS students were advised to take. Turner (2008) evaluated this programme by comparing students' diagnostic test results, uptake in summer support, and competency test results. They found that those who used the support as suggested scored significantly higher in the competency test.

Predicting performance is a common use for diagnostic test results—for example, both Lee et al. (2008) and Ahlgren Reddy and Harper (2013) (also Harper and Ahlgren Reddy, 2013) consider this too. Lee et al. (2008) used regression to predict first-year students' grades at Loughborough University, England and found diagnostic test results, using MSS, and the number of statistics modules studied at A-levels were statistically significant. Ahlgren Reddy and Harper (2013) and Harper and Ahlgren Reddy (2013) looked at both total scores and individual items from the Assessment and Learning in Knowledge Spaces system used at the University of Illinois, USA. They identified quiz items which are related to successful and unsuccessful course outcomes for students with algebraic manipulation proving a key item for success.

Mullen et al. (2024) present a scoping review of literature focusing on the impact MSS has on students. Of the 136 studies included in the review, 38 used diagnostic test results in their evaluation of MSS. The two most pertinent included studies to this paper's research questions will now be discussed. Berry et al. (2015) studied two years of attendance data, 2011/12 and 2012/13, from the MSC at Maynooth University, Ireland. They categorised students into "at-risk" and "not-at-risk" via their diagnostic test results (33.33% or less indicated at-risk) and/or Leaving Certificate (LC) mathematics grade (an Ordinary Level B grade or lower indicated at-risk). Their results revealed that attendance at the MSC was independent of students' at-risk status but that at-risk students spent significantly more time in the MSC than the not-at-risk students. Multiple regression analyses using each year of data to predict students' final mathematics module score were completed. Central Application Office (CAO) points (conversion of secondary school terminal examination grades for university matriculation), diagnostic test scores, and time spent in the MSC were significant factors in 2011/12. CAO points, diagnostic test scores, and the number of MSC visits were significant in 2012/13. Both models estimated a positive coefficient for the MSC variable indicating use of the MSC benefited students' academic performance. The 2011/12 regression model explained approximately 39.7% of the variance in the data while the 2012/13 model only explained approximately 15.6%. Still, the results found by Berry et al. (2015) indicate how LC grades/CAO points, diagnostic test result, time in/visits to the MSC, and final mathematics module results interacted.

Jacob and Ní Fhloinn (2019) presented the results of a logistic regression model based on 12 years of data (2004/05 to 2015/16) from 10,504 Dublin City University students. Students' diagnostic test results, number of MSC visits, LC mathematics grades, CAO points, and mathematics modules studied, were collated to predict whether students would pass or fail their mathematics module. MSC visits were categorised into zero, one, two to five, six to ten, 11-14, and 15 or more visits. LC grades were organised as six categories: Higher Level A or B, Higher Level C, Higher Level D, Ordinary Level A, Ordinary Level B, and Ordinary Level C or below. Diagnostic test results were categorised in intervals of 10%: 90-100%, 80-89.99% and so on, apart from the lowest interval [0%, 20%). Similar to MathsFit, there were five first-year non-specialist mathematics modules A–E involved. The binary dependent variable was pass or fail. The statistically significant model had an accuracy of 79.9%. The key finding was that all MSC visit categories were significant with odds ratios greater than one, meaning those who visited the MSC had significantly higher odds of passing their module than those who did not. The odds ratios ranged from 1.632 for one visit to 13.778 for 15 or more visits, meaning 1.632 times higher odds to 13.778 higher odds for MSC visitors compared to non-visitors while keeping all other variables constant. All LC grade categories had significantly higher odds of passing compared to Ordinary Level C or below grades and the CAO points variable was also significant indicating higher CAO points implied higher odds of passing. Only two of the diagnostic score categories, [30%, 40%) and [40%, 50%) were not significant in the model. The other score categories indicated significantly higher odds of passing in comparison to the [0%, 20%) category. The logistic regression model was a significantly better fit than the null model, it passed the Hosmer and Lemeshow test for goodness of fit, and explained approximately 42.4% of the variation in the data. Jacob and Ní Fhloinn (2019) thus confirmed what was hypothesised—students who have higher previous mathematical achievement, better diagnostic results, and more MSC visits than others, have higher odds of passing their mathematics module.

More recent mathematics and statistics support research has concentrated on the change brought about by the COVID-19 pandemic which forced MSS provisions to transition to online formats. Student engagement dropped sharply with this move (Hodds, 2020; Mullen et al., 2021; Gilbert et al., 2021). Though in-person provision has returned with some online support remaining to provide both the benefits of in-person and online support as desired by students (Mullen et al., 2023), student engagement has not returned to pre-pandemic levels. Engagement with the supports offered by MathsFit, particularly how MSC engagement changed over 2016-2022, is analysed in Mullen and Cronin (n.d.b, Chapter 8) offering further evidence that student engagement with MSS has changed in the 2020s. This paper evaluates the impact of MSS offered through MathsFit during 2020-2022 to establish if the impact of MSS has changed with the change in student engagement.

9.3 Method

The design evolution of MathsFit including the multiple data collection methods is presented in Mullen and Cronin (n.d.a, Chapter 7). The relevant elements for the logistic regression analysis presented in this paper will now be outlined. MathsFit participants completed a survey before their first quiz attempt which gathered: consent to participate in the research study, gender status, international or domestic status, chosen degree, previous mathematics examination taken (e.g., Leaving Certificate, A-levels), and achieved grade and expected grade in that examination. The survey also inquired whether students thought they had covered their pre-university mathematics curriculum, were unsure of this, or thought they had not. The survey questions are included in Appendix M. Students had two attempts at the MathsFit Quiz that had three sections: Arithmetic and Trigonometry, Algebra, and Functions and Calculus. Students' best result in each section over their two attempts gave their final quiz percentage. In 2020 there were 10 questions in each section, in 2021 and 2022 there were eight questions (see Mullen and Cronin (n.d.a, Chapter 7) for details). The quiz questions are available in Appendix J. Depending on their quiz results, some students were recommended to interact with the Refresher Course (RC) and/or the MSC in their feedback emails (see Appendix K). Students' use of the online RC was recorded in all three years via tracking within the RC host website. The amount of time students spent in the RC was recorded in 2021 and 2022 but not in 2020 due to changes in the host website (see Cronin and Mullen (n.d.a, Chapter 7)). MSC visit data were provided by the MSC manager. Students' continuous assessment results and final examination results were collected via the module coordinators.

A logistic regression model (as used by Jacob and Ní Fhloinn (2019)) was created to examine how the number of MSC visits, Refresher Course use, MathsFit Quiz results, demographics, and previous education impacted students' results in terms of passing and failing their university mathematics module. The model was built using data from 12 cohorts of students, that is, the two modules that participated in 2020 (A and B) and the five modules (A, B, C, D, and E) that participated in both 2021 and 2022. The response variable was whether students passed or failed their mathematics module. Module variables were included to account for the difference between the modules. A limitation of this analysis is that programme level engagement (e.g., lecture/tutorial attendance) was not collected and therefore not included. Variable selection for the model was guided by the following criteria:

- No collinearity between variables—any continuous assessment variables that were part of the final module grade were excluded, and variables that were highly correlated with another variable were examined to choose one of a highly correlated pair of variables. Variance Inflation Factors were calculated.
- Results of backwards stepwise regression—if the model had non-significant variables they were removed one at a time and the model performance was compared when the variable was included and excluded.

The variables considered for inclusion, other than the module variable, were: gender, international status, degree choice, previous education system, previous mathematics examination result, whether students felt they covered their pre-university mathematics curriculum, MathsFit Quiz percentage result, RC use, MSC use, and if students were repeating the module. The latter four variables were collected through students' MathsFit records (as described above) and module records. The first six variables were collected through the pre-quiz survey. Gender had options: Male, Female, Non-binary, and Prefer not to say. Students also selected if they were either an international or domestic student. The degree choices available to students in the participating modules were listed and students picked one. Previous educational system options were Leaving Certificate (LC), Advanced-level (A-level (UK)), General Certificate of Secondary Education (GCSE (UK)), International Baccalaureate (IB), Mature Students Admissions Pathway (MSAP), Quality and Qualifications Ireland (QQI), Scholastic Aptitude Test (SAT USA), UCD Access, and Other. Students provided their previous mathematics examination result in an open box. Those who selected "Other" as their previous educational system were asked to provide the details along with the result they received. There were no examination systems that appeared frequently enough in answers to create a new category in the previous examinations variable. Students' previous mathematics results were converted to a nine point scale guided by UCD entry requirements (University College Dublin, 2021) for all examination systems. This conversion table is available in Appendix Q. To reduce the number of variables created by these categorical variables (each category bar one becomes a binary variable in a model so a variable with four categories becomes three model variables), the previous mathematics results were reorganised into six categories with all students originally in the "1" to "4" categories regrouped into the new "1–4" category. The new category aligned with a Leaving Certificate (LC) grade of O2 or below. As only one MathsFit module had an entry criterion allowing less than an O2, this was a sensible category. The nine previous examination categories were reorganised into two categories, LC or non-LC.

To assess the performance of the logistic model as a classifier, a threshold was applied to the probabilities for each outcome. A receiver operating characteristic (ROC) curve, which plots the true positive rate (sensitivity) versus the false positive rate (specificity), was plotted to illustrate the diagnostic ability of the model. The area under the ROC curve was calculated as this highlights the discrimination of a logistic model. A perfect classifier model would have an area under the curve equal to one, whereas an area of 0.5 or less indicates the classifier is no better than random guessing. The threshold for the probabilities was then chosen by maximising the sum of sensitivity and specificity. Then, with the model using that threshold, cross tabulation of predicted and true values to identify false negatives and false positives was completed, and the accuracy of the model was calculated. The model was also assessed for goodness of fit via comparison to the null model, the Hosmer and Lemeshow (2013) test for goodness of fit, and McKelvey's R^2 (McKelvey & Zavoina, 1975).

9.4 Results

Logistic regression modelling was performed on data for 2,889 students, their data being complete for the variables: gender, international status, previous examination, previous mathematics grade, and MathsFit Quiz percentage result. The additional variables considered in the model were students' modules, number of MSC visits, and whether students were repeating the module. Chosen degree, curriculum coverage, and RC engagement were included in early models but with fewer students, due to missing data in the chosen degree and curriculum coverage variables—the reason for their exclusion will be discussed later in this section. Total time spent in the RC was also considered in the model but was not significant and this variable was not collected for both 2020 modules so was not included. Further analysis of how students engaged with the RC is presented in Mullen and Cronin (n.d.b, Chapter 8). Each variable included in the logistic regression model will be briefly presented first, before the logistic regression results, starting with the variable the model seeks to predict – module assessment result.

Module assessment in all five participating modules over the three years included both continuous and final examination assessments. As part of MathsFit the continuous assessment (CA) results were used, where possible, to identify low scoring students in order to send reminder emails detailing the support available. Each module's assessment scheme is presented in Table 9.1 for each of the years of MathsFit.

Table 9.1: Module assessment schemes for the five MathsFit modules 2020–2022.

Module	2020	2021	2022
A	30% CA (WeBWorK) 70% Final exam (online)	30% CA (WeBWorK) 70% Final exam	30% CA (WeBWorK) 70% Final exam
B	20% CA (WeBWorK+ MF) 40% Midterm exam (online) 40% Final exam (online)	20% CA (WeBWorK+ MF) 20% Midterm exam 60% Final exam	20% CA* (WeBWorK+ MF) 20% Midterm exam 60% Final exam
C	NA	30% CA (WeBWorK) 20% Tutorial quizzes (MF) 50% Final exam	20% CA (WeBWorK) 20% Tutorial quizzes (MF) 60% Final exam
D	NA	13% CA (WeBWorK + MF) 17% Midterm Exam 70% Final Exam	13% CA (WeBWorK + MF) 17% Midterm Exam 70% Final Exam
E	NA	13% CA (WeBWorK + MF) 17% Midterm Exam 70% Final Exam	13% CA (WeBWorK + MF) 17% Midterm Exam 70% Final Exam

WeBWorK is an online mathematics assessment tool (Pizer & Gage, 1995), where lecturers may choose questions from a library, edit questions or create their own, and collate assignments. These assignments typically have a start and end date, are allocated throughout a semester, and contain questions relevant to the current or recently taught topics. The number of attempts allowed for each question is adjustable, with options ranging from one to infinitely many times. Both open and multiple choice question styles are available. As shown in Table 9.1, WeBWorK is a popular choice in UCD mathematics modules as continuous assessment and it is currently used in at least 15 large modules.

For module B, the 20% CA was calculated as the best of six results from eight WeBWorK assignments and their MathsFit percentage score. Therefore, students may or may not have their MathsFit contribution used to calculate their final mark. In modules C, D, and E the MathsFit percentage contribution is a separate item of CA so is included as 3% of their final module mark. In module C the tutorial quizzes mark (17%) was computed from the best seven from nine quiz marks. Module A students did not receive any CA marks for participating in MathsFit as per the module coordinator's wish.

Figure 9.1 presents participants' final module results, and any significant differences between them, for years of the same module. Module final results were not normally distributed, with most modules having a left skew. The modules had statistically significantly different variances (F(11)=3.41, p<.001). The Kruskal-Wallis test was used to identify differences between years of the same module and had a significant result (H(11)=405.08, p<.001, ε^2=0.12, CI=0.11, 0.15). The Dunn test was used to find the modules with differences in final results between years.

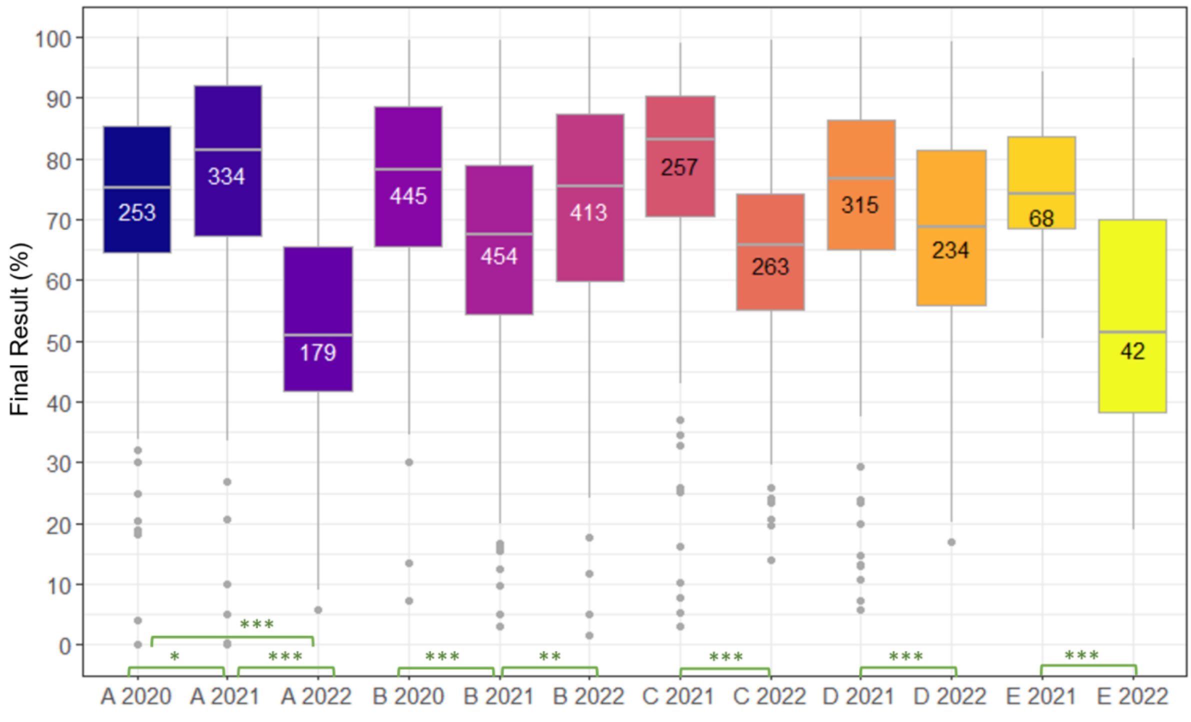

Figure 9.1: Module assessment results for the 12 MathsFit cohorts.

Figure 9.1, via the green lines with asterisks, shows all years for each module had significantly different results to each other except module B 2020 and B 2022. These differences, as well the disparities in assessment strategies meant each cohort had a variable (e.g. A 2021) in the model instead of combining three or two years of data from the same module. For the logistic regression model, students' final module results were categorised into Pass (≥40% n=2,746) and Fail (<40%, n=143).

The binary categories of students' gender (female or not), international status (international or not), previous examination category (Leaving Certificate or not), and repeat status (repeating or not) are summarised in Table 9.2 by cohort.

Table 9.2: Student participants' gender, international status, previous educational system, and repeat status per cohort.

Module & Year	Participants	Female	International	Leaving Certificate	Repeated
A 2020	251	148 (58.96%)	4 (1.59%)	237 (94.42%)	5 (1.99%)
B 2020	431	210 (48.72%)	32 (7.42%)	384 (89.10%)	9 (2.09%)
A 2021	264	166 (62.87%)	8 (3.03%)	228 (86.36%)	7 (2.65%)
B 2021	417	197 (47.24%)	29 (6.95%)	368 (88.25%)	9 (2.16%)
C 2021	240	155 (64.58%)	23 (9.58%)	202 (84.17%)	3 (1.25%)
D 2021	251	66 (26.29%)	21 (8.37%)	230 (91.63%)	5 (1.99%)
E 2021	60	26 (43.33%)	60 (100%)	0 (0.00%)	0 (0.00%)
A 2022	130	87 (66.92%)	3 (2.31%)	122 (93.85%)	1 (0.77%)
B 2022	370	192 (51.89%)	34 (9.19%)	326 (88.11%)	4 (1.08%)
C 2022	228	151 (66.22%)	25 (10.96%)	179 (78.51%)	6 (2.63%)
D 2022	212	64 (30.19%)	11 (5.19%)	201 (94.81%)	3 (1.42%)
E 2022	35	20 (57.14%)	35 (100%)	0 (0.00%)	0 (0.00%)
Total	2,889	1,482 (51.30%)	285 (9.87%)	2477 (85.74%)	52 (1.80%)

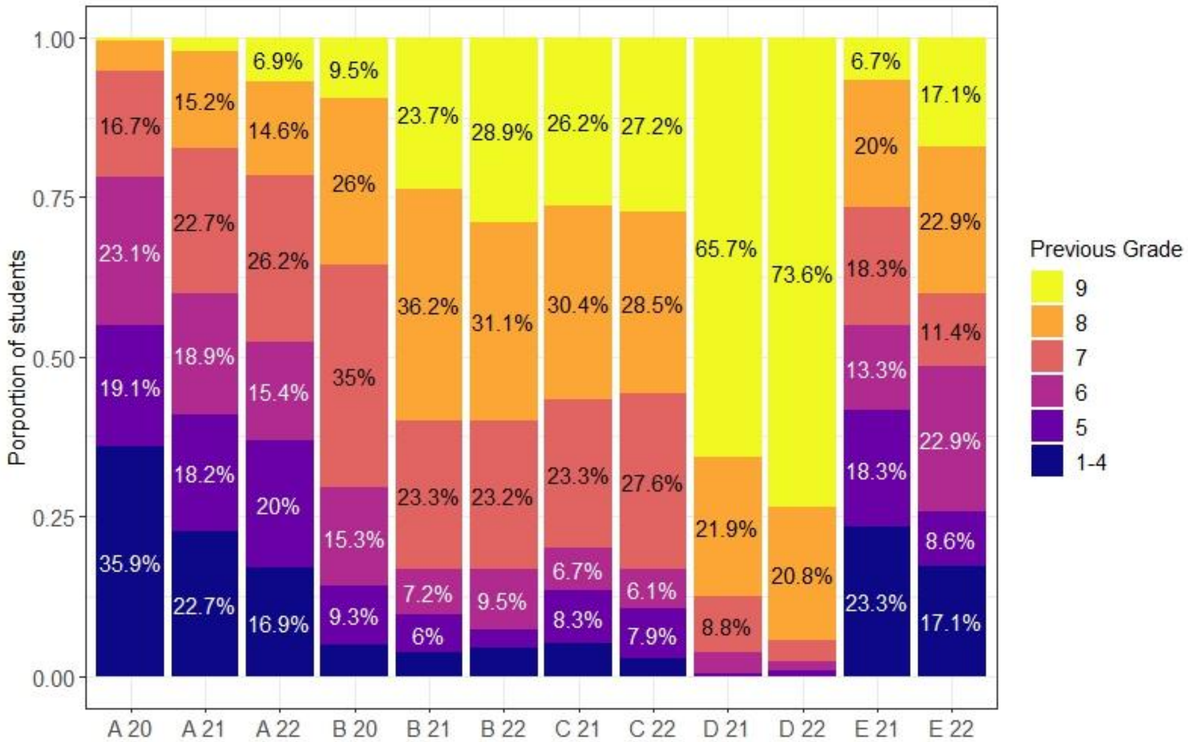

Figure 9.2: Students' previous mathematics results in six categories by cohort.

Students' previous mathematics examination results in their six categories are presented in Figure 9.2. MathsFit Quiz results were included as a percentage result – see Mullen and Cronin (n.d.a, Chapter 7) for analysis of the quiz results by section. Students' MathsFit Quiz results are presented in Figure 9.3.

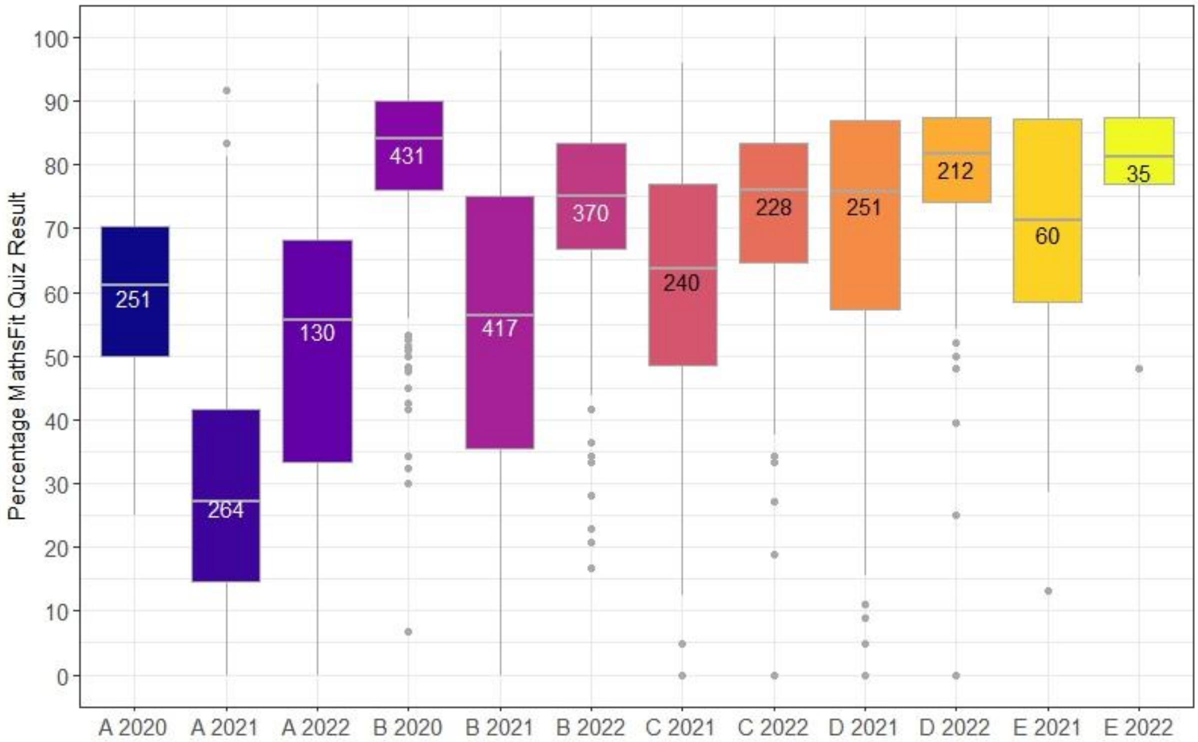

Figure 9.3: Students' MathsFit Quiz percentage result by cohort.

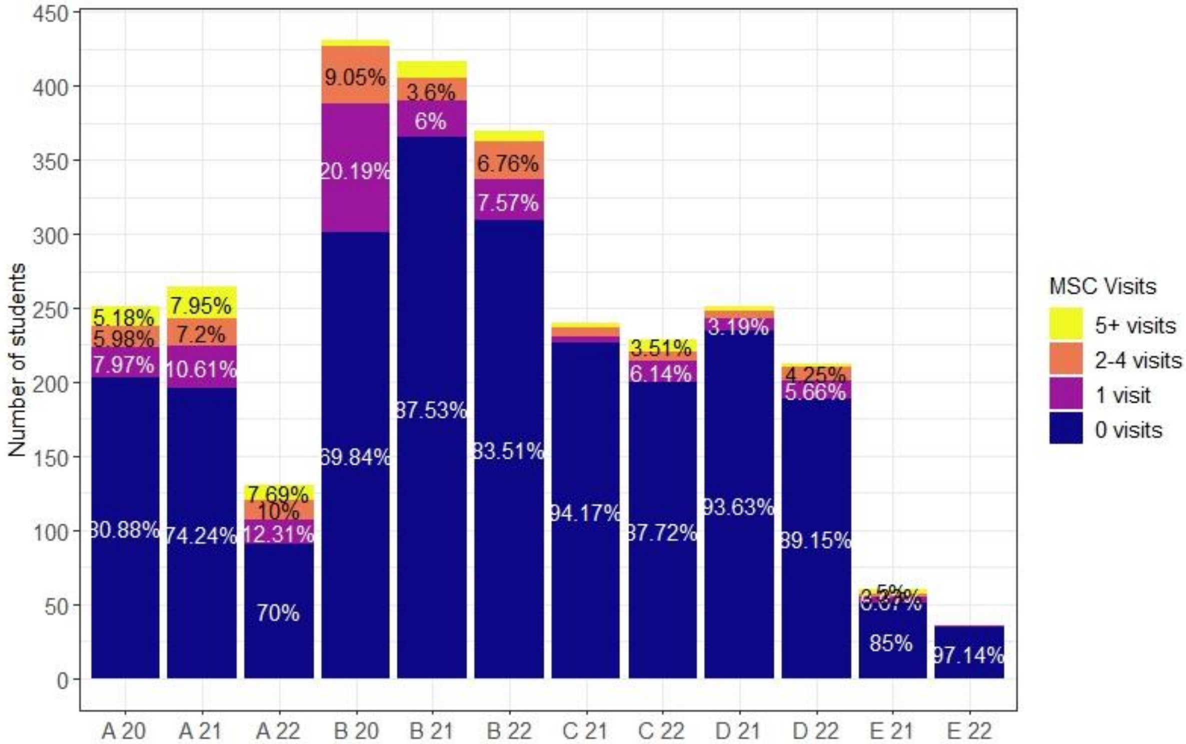

Figure 9.4: Students' MSC visits grouped into 0, 1 2-4, or 5+ visits by cohort.

MSC visits were included as count data (visit categories 0, 1, 2-4, and 5+ were tried instead of the count data, but the model was more accurate with the count data). This data is presented by cohort in Figure 9.4 with students grouped by those who visited zero times, once, two to four times or five or more times for ease of presentation. Further analysis of MathsFit participants' support engagement is detailed in Mullen and Cronin (n.d.b, Chapter 8). Variance Inflation Factors were calculated for all independent variables and none were greater than two (the recommended limit for including variables). Therefore, all independent variables could be used in the model.

The first model was the binary Pass/Fail variable as a sum of all independent variables. Then, as explained in the method section, the non-significant variables were removed one by one to see if variable removal would improve the model. The results of the best model are presented in Table 9.3. It had a classification accuracy of 82.35%, was a significantly better fit to the data than the null model ($\chi^2(22)=244.43$, $p<.001$), and the Hosmer and Lemeshow test for the goodness of fit also suggested that it was a good fit to the data (χ^2 (8) = 8.20, $p=.414$). McKelvey's R^2 indicated the model explained 63.43% of the Pass/Fail variable's variation. The variables excluded from this model were curriculum coverage, chosen degree, and binary RC engagement, as they were all non-significant in the model and the classification accuracy when they were included was 81.03%, 77.71%, and 81.65% respectively. The removal of the other non-significant variables resulted in a reduction in accuracy, so they were included. Models with interaction were examined but the interaction terms were not significant and the models were not as accurate, therefore, an additive logistic regression model was built.

Table 9.3 shows the odds ratio, the lower and upper values for a 95% confidence interval of the odds ratio, and the p-value found through z-score calculation indicating whether or not the listed variable had a significant effect on the Pass/Fail variable. There were 13 statistically significant variables namely: four of the modules; students' international status; whether a student was LC or not; previous grade categories 6, 7, 8, and 9; MathsFit Quiz percentage results; and whether a student was repeating the module. The other seven listed modules, whether a student was female or not, previous grade category 5 and MSC visits were not statistically significant.

Odds ratio values greater than one indicate an increased odds of passing, a positive effect, and values less than one indicate decreased odds of passing, a negative effect. The effect is seen as the units of a variable increase. When all variables are zero, the intercept represents the odds ratio of students who had a zero in each category. In this model this represents a student from A 2020 who is male, domestic, did not complete the LC as their last examination, received a "1-4" in their previous mathematics examination, earned zero in the MathsFit Quiz, was not repeating the module, and had not visited the MSC. That student (who does not exist in this dataset) would have an odds ratio of 0.64, meaning the odds of that student passing reduce by a factor of 0.36, according to this model.

Table 9.3: Logistic regression model variables' odds ratio, 95% confidence interval, and p-values.

Variable	Odds ratio	95% CI lower	95% CI upper	p-value
Intercept	0.64	0.24	1.73	.378
A 2021	5.14	1.83	14.48	.002
A 2022	0.44	0.19	1.06	.067
B 2020	0.74	0.29	1.91	.534
B 2021	0.72	0.31	1.66	.443
B 2022	0.64	0.25	1.66	.363
C 2021	0.78	0.30	2.01	.600
C 2022	0.17	0.07	0.40	<.001
D 2021	0.25	0.09	0.68	.006
D 2022	0.10	0.04	0.26	<.001
E 2021	1381200.59	0.00	Infinity	.976
E 2022	0.03	0.01	0.12	<.001
Female	1.21	0.82	1.78	.343
International	2.73	1.10	6.77	.030
LC	3.25	1.84	5.73	<.001
Previous grade 5	1.48	0.77	2.85	.240
Previous grade 6	2.76	1.36	5.60	.005
Previous grade 7	2.98	1.61	5.54	<.001
Previous grade 8	5.16	2.48	10.72	<.001
Previous grade 9	7.59	3.25	17.71	<.001
MathsFit Quiz %	1.03	1.02	1.04	<.001
Repeated	0.14	0.07	0.29	<.001
MSC visits	1.03	0.94	1.13	.518

Interpreting the odds ratio for the international variable (a binary variable), 2.73 indicates that an international student has 2.73 higher odds of passing their module compared to a domestic student, with all other variables held constant. Similarly, LC's odds ratio of 3.25 indicates that students who came through the Leaving Certificate system have 3.25 higher odds of passing their module than non-LC students, with all other variables held constant. Interpreting the previous two variables together indicates that students who are domestic and did not choose the LC as their previous examination system, that is, Irish mature students or Irish students coming through the QQI system, have a lower chance of passing their university mathematics module. Students who are repeating the module also have lower odds than those who are not—an odds ratio of 0.14 indicates that the odds of a repeating student passing reduce by a factor of 0.86, with all other factors held constant. The female variable is not significant meaning gender did not have a significant effect on passing, according to this model.

The non-binary categorical variables' odd ratios are interpreted in relation to the category not listed: A 2020 in the module variable and previous mathematical grade "1–4" category. The results indicate that the odds of a student who had a "6" in the previous mathematical results category were

1.48 times higher than a student who was in category “1–4”, this increased to 2.98 higher odds for “7” students compared to “1–4” students, 5.16 higher odds for “8” students, and 7.59 higher odds for students who received a “9”, compared to those with a “1–4”, all other variables being held equal. The positive relationship between previous mathematics grade and mathematics module grade is highlighted once again. The odds of a student passing in each module compared to module A 2020 is recorded by the odds ratio of each module listed. This is not of interest to this investigation, but the module variable needed to be included as a record of the differences between the modules in terms of assessment, entry requirements, and other factors. Note, the extremely large odds ratio of E 2021 is due to the fact that all students passed module E in 2021, thus, in comparison to A 2020 where some students failed, the odds of a student passing module E in 2021 are very high.

The odds ratios of the numeric variables, MathsFit Quiz percentage results and MSC visits, indicate the change in students’ odds of passing if the numeric variable increased by one. The odds of passing were predicted to grow 1.03 times larger for each additional percent earned in the MathsFit Quiz. Answering an additional question correctly, (each question is worth 4.17% or about 4% of students’ MathsFit quiz result) would indicate 1.13 higher odds of passing. The MSC visits odds ratio of 1.03 indicate a similar relationship—each additional visit would increase a students’ odds of passing by 1.03, however, the MSC visit variable was not significant thus the lower bound of its odds ratio was less than one, unlike the MathsFit Quiz results’ lower bound of 1.02. The effect of MSC visits is uncertain, according to this model.

9.5 Discussion

The results of the logistic regression model indicate overall, with demographic factors considered, use of the supports suggested by MathsFit were not significant in predicting students’ mathematics module success. This is in strong contrast to Jacob and Ní Fhloinn’s (2019) logistic regression model results where MSC visit categories were associated with significantly higher odds of passing, and previous impact analysis of UCD MSC data where visiting the MSC significantly improved students’ mathematical and statistical grades (Mullen et al., 2021). This result should be contextualised within the time frame data was collected: the academic years 2020/21–2022/23 when not only MSS services but higher education teaching and learning was in a state of flux due to the pandemic. Focusing on the MSC, student engagement decreased sharply in March 2020 and while it has increased slowly since, within 2020/21–2022/23, engagement was much lower than in previous research studying MSS impact. The engagement of these MathsFit participants is examined in Mullen and Cronin (n.d.b) revealing the statistically significant lower engagement with the MSC for all five MathsFit modules except module B in 2020 when comparing 2015/16-2019/20 to 2020/21-2022/2023. RC engagement has no comparison, due to it only being introduced with MathsFit, but its lack of significance leading to it being excluded from the final model was unexpected. How students were taught and assessed also changed within these years, as explained in the results section. The MathsFit supports offered, the MSC and RC, not having the expected statistically significant impact on students' module results is perhaps less surprising in this context but still cause for further investigation. Research into support impact on future MathsFit students and on students from other modules within 2020/21–2022/23 is needed to ascertain if this result is specific to these modules and years or a more widespread issue.

The regression model was a good classifier (82.35% classification rate) and explained 63.43% of the variability of the data. It was, however, limited by the lack of programme level engagement variables, for example, a lecture/tutorial attendance variable. This research into the impact of the MathsFit variables (particularly MSC visits) on students' pass/fail outcomes is also affected by self-selection bias, as many other MSS evaluation studies have been, as discussed in Mullen et al. (2024) and by Büchele and Schürmann (2023). Accounting for this bias would have required redesigning of the data collected for MathsFit which was not feasible within the timeframe of this research. Future research in this area would benefit from this consideration during the design process. For example, collection of more variables about student engagement as a whole (e.g. lecture attendance) would facilitate use of the propensity scoring method which requires larger numbers of variables to be accurate (Herzog, 2014).

Looking at the significant variables in the logistic regression model, students' MathsFit Quiz percentage result was a significant predictor of students' module result. This is in line with previous research into diagnostic tests' predictive power (Ahlgren Reddy & Harper, 2013; Harper and Ahlgren Reddy, 2013; Lee et al., 2008). As can be expected with a diagnostic test (Jacob and Ní Fhloinn, 2019; Berry et al., 2015) the higher a student scored in the MathsFit Quiz, the higher the odds that they passed their module. Further analysis of students' MathsFit Quiz results is presented in Mullen and Cronin (n.d.a, Chapter 7).

Higher grades in previous mathematics examinations was, unsurprisingly, significant in increasing students' odds of passing their module – this has been shown in many MSS impact studies (Mullen et al., 2024). The previous impact study of the UCD MSC found that using the MSC moderated this positive relationship between Leaving Certificate mathematics grades and university mathematics and statistics modules closing the achievement gap between lower and higher achieving students (Mullen et al., 2021a). Interaction between variables was considered in building the logistic regression model, but the model was less accurate with interaction variables included. MathsFit was built with this impact of the MSC in mind, seeking to identify via diagnostic testing those who would most benefit from support to aid their mathematics module success.

International status was significantly associated with higher odds of passing as was completing the Leaving Certificate instead of other education systems. The combination of these indicate concern for domestic students from alternative education systems – those coming through the QQI system and mature access students. Analysis of variance of students' module results with respect to their previous education system (see Appendix S) found QQI students scoring significantly lower than students from other educational systems in four of the twelve cohorts, with no such differences for mature access students. In particular, 20.93% of QQI students in this dataset failed the module, compared to the overall failure rate of 5.02%. The pattern that has emerged here prompts reflection upon what could be done to further support these students as they do not necessarily use support more than their fellow students who are more likely to pass their module (Mullen & Cronin, n.d.b).

The vast majority of student participants of MathsFit in 2020/21–2022/23 did succeed in their mathematics modules, with a pass rate of 94.98% for 2,889 students. MSC use and RC engagement did not have a statistically significant impact on that success. This result is not the first of its kind, six publications in Mullen et al., (2024) found no significant impact associated with MSS. However, most MSS impact evaluations point to a positive effect. This paper is one of the first on MSS impact using data from pandemic affected years which saw changes in MSS engagement (Gilbert et al., 2021; Mullen & Cronin, n.d.b (Chapter 8); Mullen et al., 2021b; Mullen et al., 2023). This indicates that the impact of MSS may have changed with the changes in engagement. Further research involving other MSS provisions to evaluate their impact in the 2020s is needed.

9.6 Conclusion

Results from a logistic regression analysis of 2,889 students indicate that while students' MathsFit Quiz results are predictive of their module results, the supports offered by MathsFit have no statistically significant impact on students' academic success. This unexpected result is one of the first using data from the 2020s prompting questions about the effect of recent decreases in MSS engagement. The significant demographic variables from the regression model highlight a need to support domestic students from non-Leaving Certificate educational routes, especially those with lower prior mathematics examination results. The non-statistically significant results found in this study indicate a change has occurred in MSS impact alongside the recorded decrease in engagement. Further research into the current engagement with and impact of MSS is needed to establish if this is a time and location specific issue or a new trend in MSS evaluation.

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10 Research Overview and Conclusions

This chapter provides a critical and theoretical overview of the work presented in chapters 2–9, considers its limitations and contributions to literature, and points toward future research. An answer will be provided for the overarching research question guiding this thesis: how do students engage with mathematics and statistics support, what affects this engagement, and what impact does this engagement have? The research contained in this thesis was conducted at a time of unprecedented change in mathematics and statistics support and the wider higher education community. Through the lens of evaluation of MSS impact on students, the changes in MSS caused by the pandemic, especially in UCD, have been documented. The strands of this mathematics and statistics support research—evaluation of its impact on students, online and hybrid formats of MSS, and engagement with non-specialist students through MathsFit—will now be woven together to generate conclusions and suggest future work.

10.1 Research Overview

This thesis presents a collection of publications investigating students' engagement and experience of mathematics and statistics support (MSS) and evaluating its impact. Four distinct strands of the thesis – Chapter 2 evaluates the Maths Support Centre (MSC) at UCD; Chapter 3 presents the first ever scoping literature review of MSS evaluation; Chapters 4, 5 and 6 investigate online and hybrid MSS; and Chapters 7, 8, and 9 study engagement with and evaluation of MSS through MathsFit – collectively answer the overarching research question: how do students engage with mathematics and statistics support, what affects this engagement, and what impact does this engagement have?

A range of student engagement with MSS was studied in the presented research due to the changing nature of MSS during 2020-2023. The moderation analysis in Chapter 2 was conducted on MSC visit data from 2015 to 2019 when students engaged with the in-person drop-in centre without appointment. Visitor numbers were high at this time, with an average of 5,500 student visits annually. Chapters 4 and 5 document the change in engagement that occurred when MSS could only be provided online from March 2020-May 2021. An appointment-based system was introduced. Student engagement reduced considerably. Those who engaged online reported difficulties with communicating mathematics and missed interactions with their peers and tutors. They appreciated the interaction and support available through online MSS. Tutors reported more business-like interactions in some cases and taking on more pastoral roles in others. Chapter 6 revealed that students would like to engage with a hybrid MSS service, that is, both in-person and online, though with a definite preference for in-person MSS. It also confirmed similarities and differences between in-person and online MSS in aspects such as quality of tutoring and ease of communicating mathematics. Students' reported preferences were not reflected in their MSC engagement. MSC online support use decreased as restrictions on in-person support reduced allowing an increase in-person support use. Chapter 8, focused on students' engagement with the MSC and the MathsFit Refresher Course, highlighted the lower engagement levels with the MSC in 2020-2022 compared to pre-2020. Student interview and survey feedback indicated students had positive experiences in the in-person MSC though the centre could be busy and noisy. Students used the newly designed Refresher Course, especially when given class time to do so, but spent more time in the sections they scored highly in the MathsFit Quiz than in those they scored poorly in despite contrary advice. Overall, this research shows that students are now engaging with MSS less than in the pre-pandemic period. Those that engage are having positive experiences, as is usually reported based on the findings of Chapter 3, but advantages and disadvantages of both in-person and online MSS engagement have been identified.

The pandemic and the required move to provide online support clearly impacted student engagement. Both Chapter 4 and Chapter 8 record the decrease in student engagement with the MSC, particularly when only online support was available. The previous average of 5,500 annual student visits almost halved, with an average of 2,500 annual visits in 2020/21 to 2022/23. Why students did not engage with online MSS was not explicitly explored in this research. However, interviews conducted with students who engaged indicated that their peers were overwhelmed in the solely online learning environment and did not wish to engage in further online learning. It was hoped, particularly as students indicated a preference for a mix of online and in-person support in Chapter 6, that MathsFit, a hybrid diagnostic and support programme, could prompt greater student engagement, particularly from those who required it most. As Chapter 7 describes, MathsFit was designed to identify students who would especially benefit from MSS through a diagnostic test. Results from Chapter 2 indicated that those with lower than average prior Leaving Certificate mathematical results and those who visit the MSC more frequently gain the most benefit, in terms of higher mathematics module results, from using the MSC. Thus, personalised feedback emails advised those who scored poorly on the MathsFit quiz to visit the MSC. An online Refresher Course was also provided to facilitate more independent revision of previously learned topics for students. Yet, MathsFit did not have the expected impact on student support engagement. Chapter 8 reveals a large gap between the percentage of students who were advised to use the MSC, based on their quiz performance and those who actually visited, and a smaller (particularly in 2022) gap between the number of students who were advised to use the Refresher Course and the number that did. Students in MathsFit modules did visit the MSC more than students in other first-year modules that were not involved in MathsFit but it was not the large change in engagement envisaged. In summary, this research shows that the enforced move to online support and learning decreased MSC engagement and MathsFit, a diagnostic and support programme, had a small positive impact on MSS engagement.

The impact analysis using moderation presented in Chapter 2 indicated that visiting the MSC benefited students, especially those with lower than average Leaving Certificate mathematics results. As expected, students who visited more frequently benefited more. This significantly positive impact of students' MSS engagement has been found in other studies as evidenced in Chapter 3. The scoping review included 148 publications that involved MSS evaluation, most of which reported positive feedback from students, if not significant results about the positive impact MSS has on students' academic achievement, mathematics confidence and retention among other effects. However, greater reporting rigour and more robust methodologies are needed to firmly establish this positive effect. This is especially clear from this research with the non-significant effect of the MSC and Refresher Course on students' odds of passing their mathematics module reported in Chapter 9. Neither support offered by MathsFit, Refresher Course use and MSC visits, were significant in the logistic regression model. The reason for this is uncertain with the changing modes of MSS in the years analysed (2020-2022), the design of MathsFit, and the change in MSC engagement all potentially playing a role. The results of Chapter 9 contrast with those of Chapters 2 and 3, creating an uncertain conclusion about MSS impact based on this thesis.

In summary, a change in how students engage with MSS due to changes in MSS format has been found. MathsFit only had a small impact on decreased student engagement. Visiting the MSC had a significant positive effect for students' mathematics grades in 2015-2019 but no significant effect was found for either the MSC or Refresher Course in 2020-2022. A positive MSS impact is indicated by published research internationally though more robust methodology and reporting is needed.

Much of the answer to the overarching research question of this thesis was unexpected as the global events at the time had a large influence on MSS provision and student engagement. An evaluation of past (Chapter 2) and present MSS engagement with a newly implemented diagnostic and support programme (Chapters 7, 8 and 9) alongside a scoping review to establish MSS impact internationally (Chapter 3) was planned. This evolved to include an investigation into online and hybrid MSS (Chapters 4, 5 and 6). This investigation was necessary as the small amount of research that existed on online MSS indicated many disadvantages, and student preferences about hybrid MSS were unknown. To understand student engagement through the MathsFit programme which recommended that students engage with online support (especially during 2020 and 2021), online MSS had to be studied. Throughout 2020 most MSS provisions were in similar situations, attempting to provide online support with little guidance on what was best practice. The collaboration with MSS practitioners from Western Sydney University was born from a shared need and desire to research students' and tutors' experiences of online support and a decision that collaboration would be more effective. Although differences between the MSS provisions of UCD and Western Sydney University were acknowledged from the beginning of the collaboration, it was assumed that the nature of online support made the two MSS provisions more similar than not. The research question of Chapter 4 built on this assumption seeking common issues for both universities pertaining to the use and future of online MSS, guiding the study to find commonalities between the two universities that therefore may be applicable to many MSS provisions. Both tutors and students were included in the qualitative study to ensure a comprehensive representation of the online MSS experience, which was new to both groups. Results from both groups and both universities overlapped considerably and hence were presented together. Differences as well as commonalities were found in both the online qualitative and hybrid quantitative investigations due to each university's context. However, these proved to be a strength of the investigation, identifying how students' contexts impacted their support preferences, alongside the greater sample size and broader reflection gained through this collaboration.

Despite the severe changes in MSS operation during the course of this research, the original objective of studying MSS engagement and impact was achieved. Results have provoked much reflection on the changing nature of teaching, learning and support in a pandemic and post pandemic context. How this applies to future MSS research and practice will now be outlined.

10.2 Summary of findings

The different foci of each chapter of this thesis mean that the findings apply to multiple contexts. A summary of the findings for the UCD MSC, for first-year non-specialist university mathematics students, and for the broader MSS research community follows.

In the context of the UCD MSC the findings of this thesis suggest:

1. The MSC is valued by students who use it. Students who use the MSC can achieve improved academic performance, particularly students who had lower than average Leaving Certificate mathematics results. This impact is not always statistically significant.
2. The move to exclusive online MSS significantly affected MSC use. Students visited less or not at all during the fully online MSS period and visits did not return to pre-pandemic highs by 2022 despite the creation of a mathematics diagnostic and support programme aiming to encourage student use of the MSC.
3. Teaching and learning mathematics online was difficult, especially the communication of written mathematics in the MSC context as students were not equipped with digital writing tools. Tutors had to change their pedagogy to account for not seeing students' faces and written work during student visits.
4. Students and tutors prefer the in-person MSC where they can communicate more easily, though the MSC can be busy and noisy. Once the in-person support resumed, student use of online support decreased dramatically.
5. First-year students were aware of the MSC through the MathsFit programme or before starting university. Being advised to use the MSC, based on diagnostic test results, did not always trigger students to use it.

In the context of first-year non-specialist mathematics university students the findings suggest:

1. Student engagement with a mathematics diagnostic and support programme was high, particularly when students were rewarded with module assessment marks for participation. Engagement with an online Refresher Course increased when the course was hosted within the university VLE and when students were given in-class time to explore it.
2. Students struggled with Functions and Calculus across all modules. Students from modules with higher entry requirements were more proficient at Algebra than those in modules with lower entry requirements. Students were generally proficient at Arithmetic and Trigonometry.

3. Students spent significantly more time attempting interactive practice questions than watching videos to refresh their mathematics skills. Student engagement in each section of the Refresher Course was not reflective of the advice given in feedback emails.
4. Diagnostic test results, previous mathematical attainment, previous examination system and international status were predictive of students' passing their mathematics module. Gender, engagement with the Refresher Course, and attending the MSC were not predictive based on a well-fitting logistic regression model.

In the context of wider MSS research the findings of this thesis suggest:

1. MSS evaluations point towards a positive impact on students, but this cannot be definitely stated yet. Robust evaluation methodologies taking account of self-selection bias are needed. More collaborative and funded research would assist in the further development of MSS evaluation research.
2. MSS evaluation reporting has developed from initial usage reports to scholarly contributions to wider mathematics education literature. More research development is anticipated as MSS continues to grow as a research area worldwide.
3. Student engagement with MSS, particularly during and post-pandemic has changed. Students' preferences for the format of MSS (in-person or online) is dependent on practicalities such as travel time to campus. Tutors prefer in-person MSS where diagnosing students' difficulties in real time and seeing their written mathematical work is easier.
4. MSS is still valued and highly rated by students even when online.

In summary, the findings of this thesis suggest that MSS is a highly appreciated student service that has the potential to impart many positive impacts. However, the changes caused by the pandemic-enforced move online and subsequent move back to in-person support have reduced student use of the service significantly and perhaps lessened its effects. As MSS continues to serve students, more rigorous evaluation of both the impact MSS has on its users and why students are not engaging is needed.

10.3 Limitations

The limitations of the research presented in this thesis varied by chapter because of the multiple methods approach. Sample size must be considered. Chapters 2, 7, 8, and 9 used large samples of the student population but treated students as homogeneous groups, a necessity for the analysis methods used. The results of Chapter 2 did not consider non-Leaving Certificate students. Chapters 7, 8, and 9 results were affected by missing data as only adults who consented to participate were considered, and not all participants had a full dataset. Therefore, not all students were considered in the MathsFit analysis. These chapters, especially Chapter 2, also considered a limited number of variables that do not explain the entirety of a student's experience and therefore not their academic results or their use of MSS. The results of these chapters are therefore indicative of most but not all students and consider student groups' experience instead of the individual student experience. Chapters 4, 5, 6, and 7 consider the individual student more but present data from self-selecting students, those willing to fill out a survey or be interviewed, and therefore may not be representative of the whole student population. Chapters 4, 5 and 6 consider only students who used MSS and, as discussed, the views of students who did not engage in MSS are also important to consider, particularly if the online format prevented them from engaging in MSS. In Chapter 7, while most MathsFit surveys had a high response rate, the follow-up survey, and therefore the pool of potential interviewees, was smaller and this was a limitation. Finally, Chapter 3 did not seek information from students but from publications and cast a wide net through the search of multiple sources. Nonetheless, some MSS publications may have been missed due to publication location or due to only English language publications being included.

Researcher bias must also be considered, especially in qualitative research. As an MSC tutor at UCD before and throughout this experience the researcher's personal views of MSS were both a strength and a limitation to the research. The researcher's personal experience of online MSS helped guide the design for the interviews in Chapter 4 and 5 but may have then influenced the analysis. This was mitigated somewhat with multiple coders of the interviews, but they were also involved in MSS provision. Similarly, as the chief designer of MathsFit, this and the researcher's MSC experience influenced MathsFit interviews' design and analysis. Braun and Clarke (2021) note researchers' personal biases are always present in qualitative analysis and this is why reflexivity is a fundamental part of thematic analysis. All qualitative analysis in this thesis was guided by the Braun and Clarke (2006) approach to thematic analysis so previous MSS experience was more of a strength than a limitation.

Finally, though this research focuses on mathematics and statistics support, there was a focus on the use and impact of an MSC, in particular, and also an online Refresher Course. There are other forms of support available to students, for example, their module lecturers and tutors, their peers, and online materials, that students may prefer to use. Lack of use of the forms of MSS considered in this thesis do not necessarily indicate that students are not seeking support at all. Many more factors affect students' success in university than those considered here, and the lack of consideration of these, due to the focus of most elements of this research on the impact of the MSC, limits the conclusions of this research. In particular, the effect of the COVID-19 pandemic on university teaching, learning and assessment cannot be underestimated in the consideration of students' MSS use and academic experience. For example, module assessment operated differently online and therefore student success did too. As assessment is a key reason for engagement in MSS (Gokhool, 2023), a difference in engagement could perhaps be expected. The relevancy of elements of this research may reduce as higher education resumes “normal” in-person activity, however, it was strikingly important to understand students and their MSS use in 2020-2022.

10.4 Contribution to the literature

Research presented in this thesis contributes to both MSS research and practice as will now be outlined.

Moderation analysis of over 12,000 students’ Leaving Certificate results, university mathematics module results and MSC use during 2015-2019, highlighted the positive effect UCD MSC has on students’ results, helping to close the achievement gap. Based on the results of Chapter 3, it joins a small number (Jacob & Ní Fhloinn, 2019; Jackson, 2022) of longitudinal studies on the impact of MSS.

The first scoping literature review of MSS evaluation, which brought together a collection of 148 MSS publications from 12 countries detailing ten formats of MSS, quantified MSS research in a new way and identified the need for more rigorous evaluation of MSS. The scoping review also paves the way for a potential first systematic review of MSS evaluation and greater collaboration in MSS research.

Qualitative investigations into students’ and tutors’ experience of online MSS gave a voice to their experience of learning and teaching mathematics online. Difficulties in online mathematics communication, desire for greater peer interaction, and changes in pedagogy were made clear, aiding development of strategies for online MSS in both UCD and Western Sydney University. The papers from this study were among the first more detailed reports about the experience of the rapid move to online MSS alongside Hodds (2020), Johns and Mills (2021), and Gilbert et al. (2021).

Surveys specifically targeting students who had experienced both online and in-person MSS formats, and those who only experienced online or in-person, provided further results about students’ experience of MSS and their format preferences. High quality ratings for the help received despite the format provided assurances for tutors that their work was still effective. Communication and social interaction ratings emphasised the differences between online and in-person MSS. Student preferences were informative in the organisation of UCD’s and Western Sydney University’s hybrid MSS provisions.

The design evolution of MathsFit, a hybrid mathematics diagnostic and support programme, illustrated the capabilities and limitations of Brightspace, Numbas, and Bolster Academy in hosting mathematical quizzes and practice questions. Feedback gathered about MathsFit revealed new insights from students heavily affected by the COVID-19 pandemic about timing of diagnostic tests, use of MathsFit, and awareness of the UCD MSC which influenced MathsFit design. MathsFit directly impacted students in UCD by providing the Refresher Course, personal diagnostic feedback, and raising their awareness of the MSC. It prompted development of study groups in the MSC.

Analysis of MathsFit participants' data exposed new results about students' performance in a diagnostic quiz, engagement in follow-up support, and achievement in their mathematics module during 2020/21 to 2022/23. Students' relatively high engagement with the online Refresher Course and relatively low engagement (compared to previous years) with the MSC were found to not significantly impact students' likelihood of passing their mathematics module, a contrast to previously published results (Jacob & Ní Fhloinn, 2019) and Chapter 2's findings. Insights gained about differences in module results based on students' previous education, gender, international status, and quiz performance will allow future group-specific MSC advertising and support planning to take place.

10.5 Further research

Avenues of potential future research have been identified throughout this thesis. Much of this research was conducted with the effects of the COVID-19 pandemic as a backdrop, which created discussions about online versus in-person or a blended format of MSS. Now, the requirement for online MSS is no longer a priority but the effects of the move online are still being felt. More research into how students currently interact with MSS is needed as this research and other research (Gilbert et al., 2023) suggests their approach to MSS and their wider mathematical learning may have changed.

Chapter 3 highlighted how MSS research would benefit from the development of rigorous methods of evaluation that account for the self-selection bias that naturally occurs. Propensity score matching has been used previously (Büchele and Schürmann, 2023; Herzog, 2014) and this could be implemented on a wider scale. This method, to account for self-selection bias adequately, requires more data about a student to explain their approach to learning, and other factors that influence MSS use than has been collected in MSS evaluation studies heretofore. Both Büchele and Schürmann (2023) and Herzog (2014) collected over 20 variables from over 750 students. A large-scale study collecting details of students' MSS use, broader mathematical learning, demographics, and engagement at a programme level would be of great interest. MathsFit was a step in this direction but as most data were collected at the start of the semester, important programme level engagement was not captured. Expansion to the collection of mathematics module lecture and tutorial attendance, and attainment and engagement in students' other modules in a semester would be needed to gain a fuller picture of students' engagement in MSS. Results of a study of this scale would inform MSS advertisement and planning of support initiatives to engage a greater proportion of students, especially those "at-risk" students who could most benefit.

Greater collaboration with multiple MSS provisions and their practitioners/researchers, potentially to agree on and carry out an evaluation method, would also inform future provision of MSS. As found in Chapter 3 and purposefully compared in Chapters 4, 5 and 6, MSS provisions are unique to their institutions yet share similar goals and experiences. Should such a collaboration occur, the large potential dataset, exchange of ideas between collaborators, and the range of MSS services offered, would benefit MSS practitioners (especially those not in the position to carry out independent research) and their students.

While no longer an immediate concern, the provision of online MSS requires further research, not only to facilitate students who currently depend on online services, but also as a return to wholly online MSS is not impossible, as experts fear another pandemic could occur (O'Dowd, 2024). Investigation into possible methods and tools that aid student-tutor communication of mathematical language seems to be most important, based on the results of Chapters 4, 5, and 6. A mathematical keyboard, as provided in online calculators which allows easy typing of mathematical symbols and notation, available to both students and tutors in conjunction with a shared whiteboard would greatly aid online MSS. Online communication platforms such as Zoom have evolved significantly in this regard since the early onset of the pandemic, but mathematical communication is still largely confined to the QWERTY keyboard unless a stylus and tablet/touchscreen are available. Generative Artificial Intelligence may soon change this or, at least play a part in improving online MSS. Ways to encourage student use of and greater student interaction in online MSS sessions would also be beneficial. This would overlap with the pertinent research issue of engaging the non-engaged in MSS, whether in-person or online. Repeated advertisement seems to be key (Gokhool, 2023). Further research into online MSS would require a population of students who continue to use such a service. As they presumably choose to use online MSS over in-person MSS, their use of and interaction during online MSS may be different to how students act when online MSS is their only choice. The context of such research and its participants would be key to understanding its results. A mixed methods approach where student use of online MSS is quantitatively analysed and students' experience of online MSS is explored qualitatively would be most appropriate.

MathsFit has many short and long-term future research pathways. As outlined in Chapter 7, greater analysis of the quiz data already collected would allow inference about students' confidence in answering quiz questions and potential misconceptions. Students' interactions with specific Refresher Course topics and how that aligned with their quiz answers on those topics could be investigated. When students visited the MSC and what topics they sought support on could also be studied. The three years of students represented in the collected dataset are of great interest as they include the students whose upper secondary school education was most disrupted by the pandemic.

Broader development goals for MathsFit include potential implementation of the Numbas Diagnosys system that would allow greater personalisation of both the quiz experience and the feedback it gives to students. This could also allow further research. The mastery mode of this system would allow investigation into how students use this resource, for example, how many times does a student attempt a question before giving up? If a prompt to visit the Maths Support Centre with the question was included as part of the feedback to students for an incorrect answer, would this prompt the student to visit? A similar prompt could be further integrated into the Refresher Course practice questions' feedback to investigate this question too (the MSC was advertised alongside the Refresher Course resources). Building the knowledge graph for the diagnostic mode of Diagnosys using MathsFit results alongside other quiz design techniques and then comparing students' performance to assumptions made in the design would further results about the expected and the true mathematical proficiency of students. Knowledge about students' mathematical capabilities allows support to be streamlined. More thought is also required in how best to embed MathsFit, both its proficiency quiz and Refresher Course, into the module as a whole to improve student experience.

Hyland and O'Shea (2022), in their analysis of diagnostic tests used in Irish higher education institutions, proposed a shared diagnostic test (or bank of tests) between Irish tertiary mathematics departments to create a greater volume of diagnostic data ready for comparison. MathsFit, due to its online nature, is suitable for this type of project. Efforts to create a shared bank of resources for Irish tertiary students are already underway (Pfeiffer et al., 2023) as part of the Irish MSS network's reaction to the move online in 2020. Linking a diagnostic assessment to these resources would create an easy to access set of diagnostic and support resources for all Irish mathematics students. This would enable each institution's MSS practitioners to spend more time engaging with the students who need them most.

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Gilbert, H. J., Schürmann, M., Lawson, D., Liebendörfer, M., & Hodds, M. (2023). Post-pandemic online mathematics and statistics support: Practitioners' opinions in Germany and Great Britain & Ireland. *International Journal of Mathematical Education in Science and Technology*, 1–26. https://doi.org/10.1080/0020739X.2023.2184282

Gokhool, F. (2023). *An investigation of student engagement and non-engagement with mathematics and statistics support services* [Doctoral thesis, Coventry University]. https://pureportal.coventry.ac.uk/en/studentTheses/an-investigation-of-student-engagement-and-non-engagement-with-ma

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O'Dowd, A. (2024). World is woefully unprepared for another pandemic, experts warn. *BMJ (Online)*, *385*, q1355. https://doi.org/10.1136/bmj.q1355

Pfeiffer, K., Welby, M., & Crowley, J. (2023). The IMLSN online resources website: Sharing maths resources. In A. Twohill and S. Quirke (Eds.) *Proceedings of the Ninth Conference on Research in Mathematics Education in Ireland* (pp. 77–80). https://doi.org/10.5281/zenodo.8424643

Appendices

Appendix A: Scoping literature review search strings

ACM Digital Library

(Title:(college OR "further education" OR "higher education" OR "institute of technology" OR "post-secondary education" OR "postsecondary education" OR postgraduate OR postgraduates OR "tertiary education" OR "third level education" OR "third-level education" OR ("third level" AND student) OR ("third level" AND students) OR (third-level AND student) OR (third-level AND students) OR undergraduate OR undergraduates OR university) OR Abstract:(college OR "further education" OR "higher education" OR "institute of technology" OR "post-secondary education" OR "postsecondary education" OR postgraduate OR postgraduates OR "tertiary education" OR "third level education" OR "third-level education" OR ("third level" AND student) OR ("third level" AND students) OR (third-level AND student) OR (third-level AND students) OR undergraduate OR undergraduates OR university) OR Keyword:(college OR "further education" OR "higher education" OR "institute of technology" OR "post-secondary education" OR "postsecondary education" OR postgraduate OR postgraduates OR "tertiary education" OR "third level education" OR "third-level education" OR ("third level" AND student) OR ("third level" AND students) OR (third-level AND student) OR (third-level AND students) OR undergraduate OR undergraduates OR university))
AND
(Title:(("academic development" AND math*) OR "calculus centres" OR "calculus centers" OR "calculus centre" OR "calculus center" OR ("learning assistance centre" AND math*) OR ("learning assistance center" AND math*) OR ("learning assistance centres" AND math*) OR ("learning assistance centers" AND math*) OR ("learning development" AND math*) OR ("learning support" AND math*) OR ("math center") OR ("math centre") OR ("maths center") OR ("maths centre") OR ("mathematics center") OR ("mathematics centre") OR ("math centers") OR ("math centres") OR ("maths centers") OR ("maths centres") OR ("mathematics centers") OR ("mathematics centres") OR ("math help" AND center*) OR ("math help" AND centre*) OR "math support" OR "maths support" OR "maths supports" OR "math supports" OR "mathematics support" OR "mathematics supports" OR "mathematics learning support" OR "math learning support" OR "maths learning support" OR "mathematics tutoring" OR "maths tutoring" OR "math tutoring" OR ("maths learning" AND centre*) OR ("maths learning" AND center*) OR ("math learning" AND centre*) OR ("math learning" AND center*) OR ("mathematics learning" AND centre*) OR ("mathematics learning" AND center*) OR "stats support" OR "statistics support" OR "stats supports" OR "statistics supports" OR "tutoring center" OR "tutoring centers" OR "tutoring centre" OR "tutoring centres" OR "tutoring service") OR Abstract:(("academic development" AND math*) OR "calculus centres" OR "calculus centers" OR

"calculus centre" OR "calculus center" OR ("learning assistance centre" AND math*) OR ("learning assistance center" AND math*) OR ("learning assistance centres" AND math*) OR ("learning assistance centers" AND math*) OR ("learning development" AND math*) OR ("learning support" AND math*) OR ("math center") OR ("math centre") OR ("maths center") OR ("maths centre") OR ("mathematics center") OR ("mathematics centre") OR ("math centers") OR ("math centres") OR ("maths centers") OR ("maths centres") OR ("mathematics centers") OR ("mathematics centres") OR ("math help" AND center*) OR ("math help" AND centre*) OR "math support" OR "maths support" OR "maths supports" OR "math supports" OR "mathematics support" OR "mathematics supports" OR "mathematics learning support" OR "math learning support" OR "maths learning support" OR "mathematics tutoring" OR "maths tutoring" OR "math tutoring" OR ("maths learning" AND centre*) OR ("maths learning" AND center*) OR ("math learning" AND centre*) OR ("math learning" AND center*) OR ("mathematics learning" AND centre*) OR ("mathematics learning" AND center*) OR "stats support" OR "statistics support" OR "stats supports" OR "statistics supports" OR "tutoring center" OR "tutoring centers" OR "tutoring centre" OR "tutoring centres" OR "tutoring service") OR Keyword:(("academic development" AND math*) OR "calculus centres" OR "calculus centers" OR "calculus centre" OR "calculus center" OR ("learning assistance centre" AND math*) OR ("learning assistance center" AND math*) OR ("learning assistance centres" AND math*) OR ("learning assistance centers" AND math*) OR ("learning development" AND math*) OR ("learning support" AND math*) OR ("math center") OR ("math centre") OR ("maths center") OR ("maths centre") OR ("mathematics center") OR ("mathematics centre") OR ("math centers") OR ("math centres") OR ("maths centers") OR ("maths centres") OR ("mathematics centers") OR ("mathematics centres") OR ("math help" AND center*) OR ("math help" AND centre*) OR "math support" OR "maths support" OR "maths supports" OR "math supports" OR "mathematics support" OR "mathematics supports" OR "mathematics learning support" OR "math learning support" OR "maths learning support" OR "mathematics tutoring" OR "maths tutoring" OR "math tutoring" OR ("maths learning" AND centre*) OR ("maths learning" AND center*) OR ("math learning" AND centre*) OR ("math learning" AND center*) OR ("mathematics learning" AND centre*) OR ("mathematics learning" AND center*) OR "stats support" OR "statistics support" OR "stats supports" OR "statistics supports" OR "tutoring center" OR "tutoring centers" OR "tutoring centre" OR "tutoring centres" OR "tutoring service"))

SCOPUS

TITLE-ABS-KEY (college OR "further education" OR "higher education" OR "institute of technology" OR "post-secondary education" OR "postsecondary education" OR postgraduate* OR "tertiary education" OR "third level education" OR "third-level education" OR ("third level" AND student*) OR (third-level AND student*) OR undergraduate* OR university)

AND

TITLE-ABS-KEY (("academic development" AND math*) OR “calculus centre*” OR “calculus center*” OR ("learning assistance centre*" AND math*) OR ("learning assistance center*" AND math*) OR ("learning development" AND math*) OR ("learning support" AND math*) OR ("math* center*") OR ("math* centre*") OR ("math* help" AND center*) OR ("math* help" AND centre*) OR "math* support*" OR "math* learning support*" OR "math* tutoring" OR ("math* learning" AND centre*) OR ("math* learning" AND center*) OR "stat* support*" OR “tutoring center*” OR “tutoring centre*” OR "tutoring service*")

Web of Science

(TI=(college OR "further education" OR "higher education" OR "institute of technology" OR "post-secondary education" OR postgraduate* OR "tertiary education" OR "third level education" OR "third-level education" OR ("third level" AND student*) OR (third-level AND student*) OR undergraduate* OR university) OR AB=(college OR "further education" OR "higher education" OR "institute of technology" OR "post-secondary education" OR postgraduate* OR "tertiary education" OR "third level education" OR "third-level education" OR ("third level" AND student*) OR (third-level AND student*) OR undergraduate* OR university) OR AK=(college OR "further education" OR "higher education" OR "institute of technology" OR "post-secondary education" OR postgraduate* OR "tertiary education" OR "third level education" OR "third-level education" OR ("third level" AND student*) OR (third-level AND student*) OR undergraduate* OR university))

AND

(TI=(("academic development" AND math*) OR “calculus centre*” OR “calculus center*” OR ("learning assistance centre*" AND math*) OR ("learning assistance center*" AND math*) OR ("learning development" AND math*) OR ("learning support" AND math*) OR ("math* center*") OR ("math* centre*") OR ("math* help" AND center*) OR ("math* help" AND centre*) OR "math* support*" OR "math* learning support*" OR "math* tutoring" OR ("math* learning" AND centre*) OR ("math* learning" AND center*) OR "stat* support*" OR “tutoring center*” OR “tutoring centre*” OR "tutoring service*") OR AB=(("academic development" AND math*) OR “calculus centre*” OR “calculus center*” OR ("learning assistance centre*" AND math*) OR ("learning assistance center*" AND math*) OR ("learning development" AND math*) OR ("learning support" AND math*) OR ("math* center*") OR ("math* centre*") OR ("math* help" AND center*) OR ("math* help" AND centre*) OR "math* support*" OR "math* learning support*" OR "math* tutoring" OR ("math* learning" AND centre*) OR ("math* learning" AND center*) OR "stat* support*" OR “tutoring center*” OR “tutoring centre*” OR "tutoring service*") OR AK=(("academic development" AND math*) OR “calculus centre*” OR “calculus center*” OR ("learning assistance centre*" AND math*) OR ("learning assistance center*" AND math*) OR ("learning development" AND math*) OR ("learning support" AND math*) OR ("math* center*") OR ("math* centre*") OR ("math* help" AND center*) OR ("math* help" AND centre*) OR "math* support*" OR "math* learning support*" OR "math* tutoring" OR ("math* learning" AND centre*) OR ("math* learning" AND center*) OR "stat* support*" OR “tutoring center*” OR “tutoring centre*” OR "tutoring service*"))

Proquest

Permutations of: TITLE,ABSTRACT,IF(college OR "further education" OR "higher education" OR "institute of technology" OR "post-secondary education" OR "postsecondary education" OR postgraduate* OR "tertiary education" OR "third level education" OR "third-level education" OR ("third level" AND student*) OR (third-level AND student*) OR undergraduate* OR university)
AND
TITLE,ABSTRACT,IF(("academic development" AND math[*19]) OR “calculus centre*” OR “calculus center*” OR ("learning assistance centre*" AND math[*19]) OR ("learning assistance center*" AND math[*19]) OR ("learning development" AND math[*19]) OR ("learning support" AND math[*19]) OR ("math[*19] center*") OR ("math[*19] centre*") OR ("math[*19] help" AND center*) OR ("math[*19] help" AND centre*) OR "math[*19] support*" OR "math[*19] learning support*" OR "math[*19] tutoring" OR ("math[*19] learning" AND centre*) OR ("math[*19] learning" AND center*) OR "stat[*19] support*" OR “tutoring center*” OR “tutoring centre*” OR "tutoring service*")

Due to a limit on characters (brought in between the two searches) allowing only title and abstract or title and keywords to be searched at a time, the Proquest search string had to be run nine times with the different permutations of the string, taking two of title, abstract, if for each grouping of terms (higher education terms and MSS terms). The original Proquest search string was the same as above except TITLE was TI and ABSTRACT was AB. It only had to be run once.

Pyschinfo

(second search only)
(TI(college OR "further education" OR "higher education" OR "institute of technology" OR "post-secondary education" OR "postsecondary education" OR postgraduate* OR "tertiary education" OR "third level education" OR "third-level education" OR ("third level" AND student*) OR (third-level AND student*) OR undergraduate* OR university) OR AB(college OR "further education" OR "higher education" OR "institute of technology" OR "post-secondary education" OR "postsecondary education" OR postgraduate* OR "tertiary education" OR "third level education" OR "third-level education" OR ("third level" AND student*) OR (third-level AND student*) OR undergraduate* OR university) OR KW(college OR "further education" OR "higher education" OR "institute of technology" OR "post-secondary education" OR "postsecondary education" OR postgraduate* OR "tertiary education" OR "third level education" OR "third-level education" OR ("third level" AND student*) OR (third-level AND student*) OR undergraduate* OR university))

AND

(KW("academic development" AND math*) OR “calculus centre*” OR “calculus center*” OR ("learning assistance centre*" AND math*) OR ("learning assistance center*" AND math*) OR ("learning development" AND math*) OR ("learning support" AND math*) OR ("math* center*") OR ("math* centre*") OR ("math* help" AND center*) OR ("math* help" AND centre*) OR "math* support*" OR "math* learning support*" OR "math* tutoring" OR ("math* learning" AND centre*) OR ("math* learning" AND center*) OR "stat* support*" OR “tutoring center*” OR “tutoring centre*” OR "tutoring service*") OR AB(("academic development" AND math*) OR “calculus centre*” OR “calculus center*” OR ("learning assistance centre*" AND math*) OR ("learning assistance center*" AND math*) OR ("learning development" AND math*) OR ("learning support" AND math*) OR ("math* center*") OR ("math* centre*") OR ("math* help" AND center*) OR ("math* help" AND centre*) OR "math* support*" OR "math* learning support*" OR "math* tutoring" OR ("math* learning" AND centre*) OR ("math* learning" AND center*) OR "stat* support*" OR “tutoring center*” OR “tutoring centre*” OR "tutoring service*") OR TI(("academic development" AND math*) OR “calculus centre*” OR “calculus center*” OR ("learning assistance centre*" AND math*) OR ("learning assistance center*" AND math*) OR ("learning development" AND math*) OR ("learning support" AND math*) OR ("math* center*") OR ("math* centre*") OR ("math* help" AND center*) OR ("math* help" AND centre*) OR "math* support*" OR "math* learning support*" OR "math* tutoring" OR ("math* learning" AND centre*) OR ("math* learning" AND center*) OR "stat* support*" OR “tutoring center*” OR “tutoring centre*” OR "tutoring service*"))

Appendix B: Scoping Literature Review Included Publications

Evaluation Focused Study References

Adamiak, J. P., & Sauls, R. D. (2017). Influencing mathematics students' academic success through online intervention: A case study. *South African Journal of Higher Education, 31*(3), 230-248. https://doi.org/10.20853/31-3-1573

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Breen, C., Prendergast, M., & Carr, M. (2015). Investigating the Engagement of Mature Students with Mathematics Learning Support. *Teaching Mathematics and its Applications, 34*(1), 16-25. https://doi.org/10.1093/teamat/hru027

Byerley, C., Campbell, T., & Rickard, B. (2018). Evaluation of impact of Calculus Center on student achievement. In A. Weinburg, C. Rasmussen, J. Rabin, M. Wawro, & S. Brown (Eds.), *Proceedings of the 21st Annual Conference on Research in Undergraduate Mathematics Education* (pp. 816-825). The Special Interest Group of the Mathematical Association of America (SIGMAA) for Research in Undergraduate Mathematics Education.

Byerley, C., James, C., Moore-Russo, D., Rickard, B., Mills, M., Heasom, W., Oien, J., Farthing, C., Burks, L., Ferreira, M., Mammo, B. & Moritz, D. (2020). Characteristics and Evaluation of Ten Tutoring Centers. In S. Karunakaran, Z. Reed & A. Higgins (Eds.), *Proceedings of the 23rd Annual Conference on Research in Undergraduate Mathematics Education* (pp. 70-78). The Special Interest Group of the Mathematical Association of America (SIGMAA) for Research in Undergraduate Mathematics Education.

Carroll, C. (2011). Evaluation of the University of Limerick Mathematics Learning Centre [BSc dissertation, University of Limerick]. https://mathcentre.ac.uk/resources/uploaded/evalmaths-l-centrelimerickcarrollgillpdf.pdf (mathcentre.ac.uk)

Carroll, C., & Gill, O. (2012). An innovative approach to evaluating the University of Limerick's Mathematics Learning Centre. *Teaching Mathematics and its Applications: An International Journal of the IMA, 31*(4), 199-214. https://doi.org/10.1093/teamat/hrs008

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Edwards, A., & Carroll, D. (2018). Predictors of demand for mathematics support. In E. Bergqvist, M. Österholm, C. Granberg, and L. Sumpter (Eds.), *Proceedings of the 42nd Conference of the International Group for the Psychology of Mathematics Education (PME42)* (Vol. 2, pp. 395-402). The International Group for the Psychology of Mathematics.

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Gallimore, M., & Stewart, J. (2014). Increasing the impact of mathematics support on aiding student transition in higher education. *Teaching Mathematics and its Applications, 33*(2), 98-109. https://doi.org/10.1093/teamat/hru008

Gillard, J., Robathan, K., & Wilson, R. (2012). Student perception of the effectiveness of mathematics support at Cardiff University. *Teaching Mathematics and its Applications, 31*(2), 84-94. https://doi.org/10.1093/teamat/hrs006

Halcrow, C., & Iiams, M. (2011). You can build it, but will they come? *PRIMUS, 21*(4), 323-337. https://doi.org/10.1080/10511970903164148

Herzog, S. (2014). The propensity score analytical framework: An overview and institutional research example. *New Directions for Institutional Research*, *2014*(161), 21-40. https://doi.org/10.1002/ir.20065

Hillock, P. W., Jennings, M., Roberts, A., & Scharaschkin, V. (2013). A mathematics support programme for first-year engineering students. *International Journal of Mathematical Education in Science and Technology, 44*(7), 1030-1044. https://doi.org/10.1080/0020739X.2013.823251

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Appendix C: Evaluation-focused studies summary tables

Table C1

Acronyms by column:
Source - Publication Type:
DS = Database Search
JA = Journal Article
IMLSN = Irish Mathematics Learning Support Network
RUME = Research in Undergraduate Mathematics Education conference
CP = Conference Proceedings
MLCL = Math Learning Centre Leaders (USA MSS organisation)
PME = Conference of the International Group for the Psychology of Mathematics Education
MSOR-C = Mathematics, Statistics, and Operations Research Connections journal
Country:
Italics indicates we assume this is the country of institution as it was not stated
Ethics sought:
NS = Not Stated
Funding source:
NSF = National Science Foundation (USA)
Internal or External Researcher:
IR = Internal Researcher
ER = External Researcher

Table C0.1: Source, reference, and institution details of the 55 MSS evaluation focused studies with time period and nature of research information.

#	Source - Publication Type	Authors & Year	Institution(s)	Country	Data Time Period	Research Aims or Questions	Ethics Sought	Funding Source	Internal or External Researchers
1	DS-JA	Adamiak & Sauls, 2017	University of South Africa, Western Cape	South Africa	2015: 2 semesters	Explicit	Yes	NS	IRs
2	DS-JA	Bebermeier et al., 2020	Bielefeld University	Germany	2013-2015	Explicit	NS	NS	IR & ER
3	DS-JA	Berry et al., 2015	Maynooth University	Ireland	2011/12-2012/13	Explicit	NS	NS	IRs
4	DS-JA	Breen et al., 2015	Dublin Institute of Technology	Ireland	2013/14	Explicit	NS	NS	IRs & ER

5	DS-JA	Duranczyk et al., 2006	General College University of Minnesota	*USA*	November 2004	Explicit	NS	NS	IRs
6	DS-JA	Dzator & Dzator, 2020	Central Queensland University	Australia	2016	Explicit	Yes	NS	IR & ER
7	DS-JA DS-JA DS-JA DS-JA IMLSN-Report	Fitzmaurice et al., 2015 Mac An Bhaird et al., 2013 Ní Fhloinn et al., 2014 Ní Fhloinn et al., 2016 O'Sullivan et al., 2014	Dublin City University, National University of Ireland Galway, National University of Ireland Maynooth, University College Dublin & University of Limerick. Institute of Technology Tralee, Institute of Technology Carlow, Institute of Technology Blanchardstown, & Institute of Technology Tallaght	Ireland	Semester 2 2010/11	Explicit Explicit Explicit Explicit Explicit	NS NS NS NS NS	NS NS NS All-Ireland Society for Higher Education & National Digital Learning Repository NS	ERs ERs ERs ERs ERs
8	DS-JA	Gallimore & Stewart, 2014	University of Lincoln	UK	2008-2009	Explicit	NS	NS	IRs
9	DS-JA	Gillard et al., 2012	Cardiff University	UK	Spring 2010	Explicit	NS	NS	IRs
10	DS-JA	Halcrow & Iiams, 2011	University of North Dakota	USA	NS	Implied	Unclear	NS	IRs
11	DS-JA	Herzog, 2014	NS	NS	Autumn 2011 & Autumn 2012	Implied	NS	NS	NS
12	DS-JA DS-JA	Hillock et al., 2013 Hillock & Khan, 2019	University of Queensland	Australia	2012 2012-2018	Implied Implied	NS NS	NS NS	IRs IR & ER
13	DS-JA DS-JA DS-JA	Jackson & Johnson, 2013 Jackson et al., 2014 Jackson, 2022	La Trobe University	Australia	2011-2012 2010-2012 2010-2018	Implied Implied Implied	Yes Yes Yes	University funding NS NS	IRs IRs IR
14	DS-JA	Jackson, 2021	La Trobe University	Australia	2019-2020	Implied	Yes	NS	IR
15	DS-JA	Jacob & Ní Fhloinn, 2019	Dublin City University	Ireland	2004/05 to 2015/16	Explicit	NS	NS	IRs
16	DS-JA	Johnson & O'Keeffe, 2016	University of Limerick	Ireland	2010-2012	Explicit	NS	NS	IR & ER
17	DS-JA	Kersaint et al., 2011	Large urban university in Southeast USA	USA	Autumn 2008	Explicit	Yes	NS	IRs & ERs
18	DS-JA	Khan et al., 2020	University of Central Lancashire	UK	2017/18-2018/19	Explicit	NS	NS	IRs
19	DS-JA	Mac an Bhaird et al., 2009	National University of Ireland Maynooth	Ireland	2007/08	Explicit	NS	University funding	IRs
20	DS-JA	MacGillivray, 2009	Queensland University of Technology	Australia	2003-2007	Implied	NS	NS	IR
21	DS-JA	Maitland & Lemmer, 2011	NS	South Africa	NS	Explicit	Yes	NS	NS
22	DS-JA	Matulova, 2016	Masaryk University Brno	Czech Republic	Spring 2015 & 2016	Implied	NS	NS	IR

23	DS-JA	Myers et al., 2020	Arkansas Tech University	USA	2017	Explicit	NS	NS	IRs
24	DS-JA	Nzekwe-Excel, 2010	Aston University	UK	2008/09	Explicit	NS	NS	IR
25	DS-JA	Offenholley, 2014	City University of New York	USA	Spring 2012	Explicit	Yes	NS	IR
26	DS-JA	Parkinson, 2009	Dublin City University	Ireland	2001	Implied	NS	NS	IR
27	DS-JA	Pell & Croft, 2008	Loughborough University	UK	2004/05	Explicit	NS	NS	IR & ER
28	DS-JA	Rylands & Shearman, 2015	Western Sydney University	Australia	2013: 1 semester	No	NS	NS	IR
29	DS-JA	Rylands & Shearman, 2018	Western Sydney University	Australia	Semester 1 2014	Explicit	NS	NS	IR
30	DS-JA	Watters et al., 2022	NS	*Australia*	2014-2016	Explicit	Yes	University funding	NS
31	DS-CP	Navarra-Madsen & Ingram, 2010	Texas Woman's University	*USA*	Autumn 2008-Spring 2010	Explicit	NS	NS	IRs
32	DS-CP	Pelleg et al., 2016	Drexel University	*USA*	April 2014-March 2015	Implied	NS	NS	IRs
33	DS-CP	Richtáriková, 2015	Slovak University of Technology in Bratislava	*Slovakia*	NS	Explicit	NS	NS	IR
34	DS-Thesis	Hollinger, 2022	Rural two-year community College in Alabama Southeast	USA	2018	Explicit	Yes	NS	ER
35	DS-Thesis	Johnson, 2022	2-year institution in Florida	USA	Spring 2020	Explicit	Yes	NS	ER
36	Matthews et al.-JA DS-CP	Bamforth et al., 2007 Perkin et al., 2010	Loughborough University	*UK*	2003-2005 2003/04 & 2007	Implied Implied	NS	Additional Student Numbers funding NS	IRs IRs
37	Matthews et al.-JA	Patel & Little, 2006	Robert Gordon University	UK	1999-2003	No	NS	NS	IRs
38	Matthews et al.-Thesis DS-JA	Carroll, 2011 Carroll & Gill, 2012	University of Limerick	Ireland	NS	Explicit Explicit	Yes Yes	NA	IR IRs
39	Matthews et al.-Thesis	Patel, 2011	Robert Gordon University & University of Sheffield	UK	1998-2001, 2003-2006 & 2009	Explicit	Yes	NS	IR
40	Lawson et al.-JA	Wilkins, 2015	University of Wollongong	Australia	2013-2014	Explicit	Yes	NS	IR
41	MLCL-JA	Johns et al., 2023	Six anonymous universities	USA	Autumn 2017 & Autumn 2018	Explicit	NS	NSF conference grant	NS
42	IMLSN website-CP	Mullen et al., 2021	University College Dublin	*Ireland*	10 semesters Spring 2015-Autumn 2019	Explicit	Unclear	NS	IRs & ER

43	PME-CP	Edwards & Carroll, 2018	Swinburne University of Technology	Australia	Semester 2 2017 (July-October)	Explicit	Yes	NS	IR & ER
44	RUME-CP	Byerley et al., 2020	10 unnamed universities	USA	Autumn 2017 & Autumn 2018	Explicit	NS	NSF conference grant	IR & ER
45	RUME-CP	Byerley et al., 2018	Colorado State University	USA	NS	Explicit	NS	NS	IR & ER
46	RUME-CP	Mullins, 2022	The University of Virginia's College at Wise	USA	Autumn 2021	Implied	NS	Strategic Investment Fund	IR
47	RUME-CP DS-JA	Rickard & Mills, 2017 Rickard & Mills, 2018	Oklahoma State University	*USA*	Autumn 2015	Explicit Explicit	NS NS	NS	IR & ER IR & ER
48	Delta-CP	Intepe et al., 2019	Western Sydney University	Australia	2016-2018	Explicit	NS	NS	IRs
49	Delta-CP	Poladian & Nicholas, 2013	University of Sydney	Australia	2012 - 2013	Explicit	NS	NS	IRs
50	CETL-MSOR-CP	Dowling & Nolan, 2006	Dublin City University	*Ireland*	2003/04-2005/06	No	NS	University funding	IRs
51	CETL-MSOR-CP	Mehbali, 2017	London South Bank University	UK	Week 7, Semester 2, 2015/16 & 2016/17	Explicit	NS	NS	IR
52	CETL-MSOR-CP Matthews et al.-Thesis	Symonds et al., 2008 Symonds, 2009	Loughborough University Loughborough University and Coventry University	UK	2004/05-2006/07	Implied Explicit	NS Unclear	NS	IRs & ERs IR
53	CETL-MSOR-CP	Tariq, 2007	University of Central Lancashire	UK	2-4 weeks	Implied	NS	Higher Education Academy	IR
54	MSOR-C	Little, 2018	Robert Gordon University	UK	2012/13 & 2015/16	Implied	NS	NS	IR
55	MSOR-C	Macdonald, 2019	Glasgow Caledonian University	UK	2013/14-2017/18	No	NS	NS	IR

Table C2

Acronyms:
ANOVA = Analysis of Variance
diff. = difference
GPA = Grade Point Average
LC = Leaving Certificate (Republic of Ireland’s national secondary school terminal exam)
MSC = Mathematics Support Centre
Qual = Qualitative (data)
Quant = Quantitative (data)
sig. = statistically significant

Table C0.2: : MSS format, data collection, methodology and results of the 55 MSS evaluation focused studies (see Table 3.2 for the definitions of the data types).

#	MSS Population in Study	MSS Services in Study	Data Source	Data Type	Sample Size	Data Information	Data Analysis Method	MSS Impact on Student Outcomes
1	Six 1st year modules	Online portal and in-person tutorials	Institution/ MSS data	Institution attainment, Usage	n=423 students	In-person attendance student reported; automatic online data collection; convenience sample.	Descriptive statistics, Graphs, Wilcoxon rank sum test with continuity correction	Economics students who used blended and in-person sessions instead of online had better assignment results but no diff. in exam results. Engineering students who attended in-person session had sig. better exam results, online attendees did not. Science students using online had better exam results than the general population.
2	1st year Psychology students	Tutorials, worksheets, practice class, online enrichment materials	Institution/ MSS data, Surveys	Affective (competence), Diagnostic, Institution attainment, Usage	n=482 students, (172 complete cases)	Attendance and competence data reported by students; other data from institution records.	Descriptive statistics, Correlation analyses, Linear regressions, Path analyses	Frequency of use of all 4 MSS formats is positively correlated to self-reported competence and final statistics grade. Mediation effect of services: Tutorials sig. total and direct effect but not indirect, practice classes sig. total but not direct or indirect, worksheets no sig. effects, online materials sig. indirect not total or direct.

3	1st year Science students	Drop-in centre	Institution/ MSS data	Course, Diagnostic, Institution attainment, Pre-Institution attainment, Usage	n=797 students (724 in regression)	Attendance and LC data reported by students; diagnostic and university attainment from institution records.	Descriptive statistics, ANOVA, Mann Whitney U, Chi-squared test, Graphs, Multiple regression, 2-step cluster analysis	2011/12 Time spent in MSC sig. in regression of attainment (R^2=0.397) with LC points and diagnostic test scores. 2012/13 Number of MSC visits sig. in regression (R^2=0.156) with LC points and diagnostic test scores. Cluster analysis of at-risk groups: subgroups with lowest attendance preformed worst. At-risk students were more likely to attend and stay for longer than not-at-risk students, & at-risk users do better academically than at-risk non-users.
4	Mature students	Drop-in centre	Focus groups, Institution/ MSS data	Institution attainment, Qual, Usage	Qual: n=14 students, Quant: n=20 students	Focus group recruitment unclear; exam & attendance data source unclear.	Descriptive statistics, Fisher exact test, No qual method given, t-test.	Qual: MSS helped them keep up with classes, especially those with basic skills. Quant: MSS users had non sig. higher mean marks and no user scored under 60% (non sig.).
5	Developmental mathematics students	Drop-in centre, peer tutoring	Surveys	Affective (confidence), Demographics, Institution attainment, Usage	n=298 responses	49% response rate; part of wider institution survey.	Descriptive statistics, Chi-squared test	MSS effect on confidence varied sig. by autumn grades: B & C students gained more confidence than others. A or D+/Incomplete students had greatest percentage of no gain in confidence. African/African Americans showed higher percentages of passing grades with increased use. The failure rate for European Americans increased as usage increased.
6	Mature (>21 years old) and traditional on-campus users	Drop-in centre (5 campuses), online discussions, online video calls, workshops	Surveys (includes modified version of Carroll and Gill (2012) attitude questions)	Affective (attitude towards mathematics), Demographics, Qual	n=62 responses (including 2 incomplete)	23% response rate; distribution method not described; questionnaire Likert questions had Cronbach's alpha=0.719.	Descriptive statistics, Chi-squared test, Cronbach's alpha, Qual categorisation	51.52% of students influenced by MSS to continue their undergrad studies, MSS changed 42.59%'s opinions about mathematics and statistics & 46.3%'s study habits. Mature & traditional students had sig. diff. in answers to change in study habits & opinion of mathematics & statistics, and confidence. Sig. diff. between full & part-time students in change in study habits. No other sig. diff. (full v part time, male vs female, course perception, 3+ visits). Comment categories include: Satisfaction with MSS, Attitude of student (positive effect).

7	1st year service mathematics students	9 different MSS services including drop-in centres, workshops, resources	Surveys	Affective (confidence), Course, Demographics, Institution attainment, Pre-Institution attainment, Qual, Usage,	n=1,633 students (587 users + 1,041 non-users + 5 missing data observations)	Minimum response rate of 25% for universities and 28% for institutes of technology; data is all student reported; missing data strategy present; physical distribution and collection of the paper based survey may differ in the nine locations.	Descriptive statistics, Chi-square test, General Inductive Analysis for open questions	56% of 539 users found MSS extremely/quite helpful with their confidence in mathematics, 6 comment categories: very good/ helpful to know it's there, made maths doable, weak at maths/not confident, understanding improved, didn't go enough, & confidence not an issue. 57% of 526 users thought MSS had a large/quite an impact on their mathematics performance, 6 comment categories: grades improved, very helpful, useful for assignments, understanding improved, didn't go enough, & results unknown. 65% of 530 users thought MSS was huge/some help with coping with the mathematical demands of their course, comments mainly about helpfulness. 125 of 567 students considered dropping out due to mathematics difficulties & 62.7% of 110 the potential drop outs, thought MSS had influenced their decision to stay with 5 categories of comments: importance of MSS received, encouragement received in MSS, positive impact MSS had on confidence, increased understanding of mathematics as a result of MSS, & miscellaneous. Only sig. gender diff. in how MSS helped with courses' mathematical demand, females more likely to choose 'huge help' or 'no help at all' & males more likely to choose 'not much help', 'average' or 'quite helpful'.
8	1st year Engineering students	Weekly timetabled sessions part of individual learning programs	Institution/ MSS data, Surveys	Diagnostic, Institution attainment, Qual, Retention, Usage	n=44 students	Survey design not described; quant data collection not described.	Descriptive statistics, Correlation analysis, Graphs, No survey data analysis method given	Higher retention than national benchmark data, r=0.25 between diagnostic and exam results for minimal support needed group, r=0.58 for students who needed and used support, r=-0.05 for students who needed and didn't use support, surveys showed high scores in understanding and interest in mathematics-related subjects and anecdotal evidence confirms high satisfaction with the MSS.
9	All spring 2010 MSS users	Drop-in centre	Surveys	Affective (confidence, mathematics ability), Demographics, MSC features, Qual, Usage	n=46 responses	Data all student reported; 29% response rate.	Descriptive statistics, Correlation analysis, Linear regression, t-test, Graphs	Positive student feedback, sig. diff. in ability rating and confidence rating before & after MSS use, regression model 1 (R^2=0.15): more time with tutor means sig. more diff. in ability (r=0.39), model 2 (R^2= 0.007) time not sig. to diff. in confidence (r=0.08), perceived effectiveness of tutor has sig. effect on both diff. in ability and confidence.

10	1st years College Algebra, Precalculus, Applied Calculus, and Calculus	Drop-in centre	Institution/ MSS data, Interviews	Course, Institution attainment, Pre-Institution attainment, Qual, Usage	n=151 students (81 treatment), n=13 interviews (10 treatment)	Control attendance data student reported; unclear grade data collection method; interviewees self-selected.	Thematic analysis, Descriptive statistics, t-test	No diff. in university results despite treatment group spending an hour per week in MSC for 5% of grade. Sig. positive correlations found between mean hours per week in MSC & university result for all treatment groups but not control groups. 2 qual themes: regular users felt time in MSC benefited their understanding & helped them succeed. Most said they would not attend if it wasn't part of their grade.
11	1st years undergrads	Campus mathematic s tutoring centre	Institution/ MSS data	Demographics, Institution attainment, Pre-Institution attainment Retention, Usage	n=4,887 students (780 users)	Data from institution's matriculation system & MSS electronic log.	Propensity Scores, Covariate adjusted regression, Graphs	Users accrued academic benefit in terms of grades, credits earned and enrolment persistence that would not have occurred otherwise. Visiting was 0 or 1 so some intensity of tutoring may be lost and GPA was examined instead of mathematics grade which may affect outcome.
12	1st year undergrads studying single variable calculus and linear algebra. Mainly Engineering students	Program of optional extra 1 hour tutorials for 'at-risk' students	Institution/ MSS data, Surveys, Other (text from unsolicited emails)	Institution attainment, Likert (program features), Qual, Usage	2012: n=584 students, n=24 surveys 2012-2018: n=7,486 students total, n=321 surveys	Implied attainment and attendance data collection from institution records; 75% survey response rate in 2012 and 53% over 2012-2018; survey distribution not explicitly described.	Coding of open-ended questions to find themes, Descriptive statistics, Chi-squared test, Logistic regression, Graphs	2012: 79% of 32 regular users, 38% of 14 brief users, 48% of 235 at-risk non-users, & 77% of 584 not at risk non-users passed. Program features had mean rating of 4.86 (1=Very poor, 5=Excellent) & positive comments. 2012-2018: users had a higher pass rate than non-users every semester. Sig. association between MSS use & result. No sig. diff. in probability of passing between users & non-users, but overall users have 1.8 times the odds of passing compared to non-users. Supported repeaters had 2.5 times the odds of passing compared to unsupported repeaters. Surveys: over 90% of ratings were of 4 or 5. Themes included increased knowledge & understanding of module content.

13	2010-2012: 1st year Science students 2010-2018: 1st year students of multiple degrees	Drop-in sessions, topic worksheets, commercial online programme (MyMathTest)	Focus group (academic staff), Institution/ MSS data, Surveys	Affective (confidence, mathematics anxiety etc), Course, Diagnostic, Institution attainment Likert (Helpfulness), Pre-Institution attainment, Qual, Qual – tutor/faculty, Usage	2010-12: n=445 students n=383 pre-surveys n=97 post-surveys n≥3 staff 2010-18: n=1760 pre-surveys, n=1682 students	A quarter of engaged students completed the survey (2010-2012); collection of attainment data, unclear attendance and use data collection method.	Descriptive statistics, Chi-squared test, Graphs, No qual method given	Positive student feedback, improved confidence & mathematics skills for most post-survey respondents, pass rates improved from pre- to post-test, achievement in disciplinary subjects correlated with MSS use, sig. for chemistry and biology. Students felt MSS was highly relevant, of medium use to them & high use to future students, most felt MSS usually or always helped them learn their related subjects, positive academic coordinator feedback (raises confidence). 87% students rated their mathematical confidence as improved sometimes, usually or always, & 89% rated their mathematics skills improved sometimes, usually or always, 90% felt the subject specific worksheets helped them learn their subjects sometimes, usually or always. Comments: improves confidence/skill, helpful aspects. For most subjects users' pass rate was sig. higher than non-users pass rate.
14	All MSS users in 2019 and 2020	In person 1-1 MSS (2019), Zoom online MSS (2020) & program of online testing, worksheets, and help sessions	Institution/ MSS data, Surveys	Institution attainment, Qual, Usage	n=1,358 (2019) + 1,068 (2020) users, n=350 (2019) + 457 (2020) pre-surveys	No response rates provided; survey distribution & design unclear; unclear if pass rates were from university records; attendance record method not explained.	Descriptive statistics, Chi-squared test, Graphs, No qual method given	Student quotes: online MSS is beneficial, useful; support program improved confidence, very helpful. Pass rates for 31, 34, 25, & 30 modules in semester 1 (S1) 2019, S1 2020, S2 2019, & S2 2020 compared for users & non-users, users on average were 11.3%, 9%, 15.6%, & 14% more likely to pass with 3, 6, 6, & 9 modules sig. Modules with 10+ visits had increased likelihood of users passing: 12.6%, 14%, 16.1% and 19%. 82% of 17, 83% of 29, 56% of 9, & 95% of 21 modules had equal or higher pass rate for support program users who were on average 8%, 9%, -4%, & 12% more likely to pass.
15	Five 1st year service mathematics modules	Drop-in centre, revision & refresher classes	Institution/ MSS data	Course, Diagnostic, Institution attainment, Pre-Institution attainment, Usage	n= 10,504 students	Unclear if data is student-reported or from university records.	Descriptive statistics, Correlation analysis, Logistic regression	Odds of one visit students passing were 1.63 times higher than non-visitors and 15+ visitors were almost 14 times higher (assuming other factors remain constant). Sig. pass/fail regression model with sig. independent variables of diagnostic test scores, total visits (in categories), LC mathematics grade, LC points, and mathematics module. Model had 79.9% correct classification and R^2=0.424.

16	Mature, Technology & Science students	Bridging course	Institution/ MSS data, Surveys (adapted Mathematics Self-efficacy Scale),	Affective (confidence/self-efficacy), Diagnostic, Institution attainment, Retention, Usage	n=53 pre- & post-surveys n=2 modules 2010-12: 52 users, 125 non users	100% response rate but small population; Survey design and description explicit; implied official exam records collected.	Descriptive statistics, one-way ANOVA, Tukey post-hoc test	Increase in mean mathematics self-efficacy for all: week 1 only (n=29), week 2 only (17), and week 1 & 2 attendees (7). Biggest diff. for week 1 & 2 students: longer in bridging course = greater self-efficacy. Users have higher mean diagnostic results than mature non-users both modules 2010 -2012, except 2011 Science. 2010 Technology users had sig. higher diagnostic results. Users' final exam averages only exceeded non-users in 50% of the 2 modules' exams. 10 user dropouts, 34 non-user mature student dropouts.
17	2 of 7 group sections of undergrad College Algebra course	Online tutoring (a)synchronous with virtual whiteboard	Institution/ MSS data, Pre- & post-skills assessment, Surveys	Affective (help seeking, mathematics usefulness, confidence), Diagnostic, Institution attainment, Retention	n=341 pre- + post-tests (195 treatment) n=305 pre- & post-surveys (127 treatment)	Cronbach's alpha calculated for attitude surveys (0.92) and it's sections; unclear how online attendance logs were gathered.	Descriptive statistics, Data checked for model assumptions, t-test, ANOVA	No sig. diff. between pre- and post-test regardless of control or treatment (control higher (not sig.)). In the treatment group users had sig. higher average gain than non-users but a small effect size. Users had higher attitude scores than non-users and the control group but a small effect size. 68% of control group, 85% of treatment group (users and non-users) and 98% of users took the final exam.
18	1st year Engineering students	1-1 MSS after diagnostic testing, 1 hour/week	Institution/ MSS data	Diagnostic, Institution attainment, Usage	n=33 (17/18)+ 43 (18/19) 'at-risk' and/or users.	MSS administered diagnostic; design not provided; unclear attainment data collection method.	Descriptive statistics, Paired t-tests	Mean diff. between pre- and post-diagnostic test (after 10 weeks of MSS) was 29.2% in 17/18 (sig.) & 20% in 18/19 (t-test result not reported). In 17/18 60% of users (n=20) passed & 38% of 'at-risk' non-users (13) passed. In 18/19 83% of users (24) passed & 21% 'at-risk' non-users (19) passed.
19	1st year Arts and Science students	Drop-in centre	Institution/ MSS data	Diagnostic, Institution attainment, Pre-Institution attainment, Usage	n= 201 arts + 254 science =455 students	Unclear if data is student-reported or from MSS or institution records.	Descriptive statistics, Chi-squared test, t-test, Fisher exact test	Arts users have sig. higher final marks & pass rate than arts non-users, science users have not sig. higher marks & pass rate. Arts users' final marks: sig. higher by LC grade & for just Ordinary Level users, and not sig. higher for just Higher Level users & by diagnostic 'risk' category. Science users' marks: sig. higher by 'risk' category and not sig. higher by LC grade & for just Ordinary Level users.

20	All MSS users, some focus on Nursing, Mathematics and Engineering students	Drop-in centre, 1st & 2nd year courses sessions, paper/web resources, exam prep workshops diagnostic testing	Institution/ MSS data, Other (students asked to provide written feedback),	Diagnostic, Institution attainment, Qual, Usage	n=217 nursing students (30 attendees), n=? engineering students, n=? mathematics students	Most sample sizes not reported; attendance data under recorded noted in paper; unclear qual & quant data collection method.	Descriptive statistics, Confidence intervals, Graphs, Chi-square test, No qual method described	Positive student feedback: helping achievement, improving confidence, sig. increase in nursing students' score between diagnostic & 2nd diagnostic for workshop users, non sig. increase for non-users in 2006. MSS use was sig. beneficial for engineering cohorts, both lower and higher mathematics backgrounds. Confidence intervals for mean results reach higher for users vs non-users over time for 1st, 2nd, and 3rd year mathematics courses, 1st year statistics, 2nd year linear algebra, & 1st year computational mathematics. Sig. diff. between users & non-users GPAs, sig. association between attending 1 MSS session & progression classification.
21	Foundation programme students (pre-Information Technology degree)	Peer mentors during tutorials & potentially outside of class	Focus groups, Interviews, Other (Students' written comments, field notes)	Qual, Qual – tutor/faculty	n=142 students, 79 mentees, n=10 mentors, n=5 lecturers	Clear description of data collection method.	Thematic analysis	4 themes: social adjustment of mentees in a multicultural setting, cultural diversity as both barrier and resource, role of on-campus perceptions in sustaining the tutor-mentor programme, & forging a community of mathematics practitioners. Lecturers noted improved attitude to mathematics & mathematics test results. Students recognised better conceptual understanding & developing mathematics skills but also the emotional support that helped their view of themselves as learners. Tutors thought the programme really helped the students.
22	All MSS users (mainly Economics and Admin students)	Drop-in centre & community events	Institution/ MSS data, Surveys	Course, Diagnostic, Institution attainment, Qual, Usage	n=107 surveys n=281+259 (2015+16) students n=143 users	37% response rate; survey distribution not described; other data from MSS or institution records.	Descriptive statistics, Graphs, t-test, F-test (equality of dispersions), Kolmogorov Smirnov test, No qual method given	Positive student feedback from surveys, sig. improvement in results in both theory and practical knowledge, success rate in module increased from 79.4% to 91.4% after introduction of MSS in 2016.
23	1st year students: STEM and non-STEM	Drop-in centre, added MSS to timetable	Institution/ MSS data	Institution attainment, Pre-Institution attainment	n=2,088 students, n=3 courses	All data from institution records.	Standard two-population proportion comparison tests	Stat sig. large increase in student success; measured by passing subsequent college algebra or developmental math course - after participating in modified FOCUS initiative (extra built-in tutoring hours in courses)

24	All Aston students in 2008/09	Drop-in centre	Institution/ MSS data, Surveys	Course, Qual, Usage	n=377 respondent, n=3,415 users	4% response rate; part of institution wide email survey; attendance data recording method not described.	No qual method but categorisation presented	Positive student feedback: 'integral and useful service'. 55 users' further feedback: 35/55 used 'helpful' to describe MSS, others used effective/efficient, useful, and friendly. MSS helped the development & improvement of mathematical thinking, reduced mathematics struggle, improved decision making ability, increased confidence, & improved grades.
25	Elementary Algebra students	Brainfuse online tutoring system - chat box tutor	Institution/ MSS data, Surveys	Institution attainment, Qual, Usage	n= 2,716 students (195 treatment), n=31 users, n=89 surveys	Missing grade data; 46% response rate; unclear survey distribution & design; usage data collection unclear.	Descriptive statistics, Logistic regression, Aggregation of qual responses	Pass rates similar for treatment and control groups, 45% users passed, 42% nonusers passed, overall course 48% passed. No sig. logistic regression coefficients looking at users vs non-users in terms of demographics and grades, of 19 users who answered the survey, 94.7% found it helpful, 78.9% thought it improved their grades.
26	1st year Biotechnology students	Peer tutoring by non-1st year biotech students	Focus groups, Institution/ MSS data Other (tutor reflections), Surveys	Diagnostic, Institution attainment, Pre-Institution attainment, Qual, Qual- tutor, Retention, Usage	n=20 tutored students + 46 non-tutored students	Unclear quant data collection method.	Descriptive statistics, ANOVA, Graphs	Positive student & tutor feedback, no diff. between the tutored and non-tutored groups before tutoring, sig. diff. in mathematics passing, and general progression after.
27	Five 1st year Engineering mathematics modules	Drop-in centre	Institution/ MSS data	Institution attainment, Usage	n=644 students	Unclear attendance and attainment collection method.	Descriptive statistics	Only 11 students attended more than once and failed. A number of regular visitors just passed indicating possible failure without the MSS. Number of high achievers also use the MSS - enhancement more than remedial.
28	1st year Design students	Workshops & online asynchronous MSS	Institution/ MSS data	Institution attainment, Usage	n=102 students	All data from MSS or institution records via user registration.	2-way ANOVA, Spearman & Pearson correlation	Positive correlation between students who utilise support (in person or online) and passing. 15% diff. in pass rates between users and non-users, not sig. due to small sample.
29	1st year Engineering	Workshops	Institution/ MSS data	Diagnostic, Institution attainment, Usage	n=145 students, n=84 users	All data from MSS or institution records.	Descriptive statistics, t-test, Multi-linear regression, Graphs	Engagement in the subject activities as measured by tutorial attendance & learning management system use had a positive association with final mark. Students who utilized a high level of learning support were more likely to be more engaged.

30	1st years, Medical, Biomedical, Forensic science, Science	Online mathematics skill support for chemistry/biochemistry	Institution/ MSS data, Surveys,	Course, Diagnostic, Institution attainment, Pre-Institution attainment, Usage	n=740 students	Data collection clearly described; data from online tracking and institution records.	Descriptive statistics, Chi-squared test, t-test, Cramer's V coefficient	In 2016 MSS users were sig. more successful at graphing task in final exam than non-users with a small to moderate affect, all other tasks in 2016 and other years had non sig. diff. There was a sig. diff. between users and non-users (excluding medical science students due to high results) in final grades with small effect size.
31	Mainly Mathematics majors	Drop-in centre	Institution/ MSS data	Course, Institution attainment, Usage	n=34 Calculus (18 users) + 59 algebra (43 users) students	Attendance logging changed from manual to automatic during study; institution data used.	Descriptive statistics, Pearson's correlation	Correlation between hours spent in MSS and course marks is 0.26 for calculus and 0.14 for algebra.
32	Engineering students	Engineering drop-in centre & appointments	Institution/ MSS data, Surveys	Institution attainment, Likert (understanding), Usage	n=2506 non-users +672 users =3178 students	All data collected (except surveys) via MSS records; survey response rate not provided.	Descriptive statistics, t-test	Large majority of survey respondents had greater understanding of the course material after visiting. There was not a sig. diff. between users and non-users normalised grade performance (diff. between cumulative GPA & performance in a single class)
33	1st year Mechanical Engineering students	Bridging course	Institution/ MSS data, Pre- and post-skills assessment, Surveys	Demographics, Diagnostic, Likert (Helpfulness, usefulness), Pre-Institution attainment, Retention, Usage	n=131 treatment students (131/200 users), n=227 non-users in control	Explicit diagnostic & survey data collection; no survey response rate provided; demographic data collection unclear.	Descriptive & z statistics, Shapiro-Wilk W normality test, Chi-squared, Mann Whitney U test, & Wilcoxon matched pairs test, Graphs	Treatment group did sig. better in diagnostic 2 after course than in diagnostic 1 pre course, no sig. diff. between treatment group and control in diagnostic 2. 45% of 256 students (users & non-users), found prep course very useful or useful, 32% less useful or useless (chi-squared sig.) 47% of 135 users rated the course helpful or very helpful, and 53% found it a little helpful or not helpful. No sig. diff. in students leaving course between the treatment or control groups.
34	Developmental mathematics courses	Faulkner Academic Math Excellence (FAME) Laboratory tutoring & computers	Institution/ MSS data, Other (observations), Surveys	Qual, Usage	n=23 surveys, responses, n=3 days of observations by researcher	Online survey; no response rate provided; distribution of questionnaire not explicit; MSS data collection unclear.	Qual coded and grouped in themes, Descriptive statistics	38% of respondents did not use the lab. 21% (5) of students gave reported FAME lab had impact on their overall success. 8.7% (2) reported FAME lab influenced their mathematics success at stage six. 34.8% (8) reported FAME lab had little or no impact on their success. 17.4% indicated the FAME Lab influenced their success in their developmental math course. 39.1% of the student participants stated, "The FAME Lab did not influence overall math success."

35	Non-traditional (>22 years) developmental mathematics at 2-year college students	Mathematics part of learning support centre: tutoring, access to technology, peer interaction, resources	Institution/ MSS data, Surveys (MSEAQ Deutsch (2017) mathematics self-efficacy & mathematics anxiety)	Affective (Mathematics anxiety, self-efficacy), Course, Usage	n=16 students (n=39 at start of study and decreased due to COVID-19)	Planned convenience sample; usage data accuracy relies on students logging in correctly; used validated instrument; 2nd MSEAQ completed early due to COVID.	Descriptive statistics, Paired sample t-test, Correlation, Tests of independence, normality, outliers, linearity, and homogeneity of variance.	Normality tests passed except linearity between MSS visits & preintervention mathematics anxiety. Post-intervention mathematics anxiety & self-efficacy scores were sig. lower/higher than corresponding pre-intervention scores. No sig. correlation between post-mathematics anxiety & MSS visits controlling for pre-mathematics anxiety (r=-0.322, p=0.241) or without controlling for pre-mathematics anxiety (r=-0.19, p=0.945). No sig. correlation between post-mathematics efficacy and MSS visits controlling for pre-mathematics efficacy (r=0.053, p=0.850) or without controlling for pre-mathematics efficacy (r=-0.005, p=0.985).
36	1st year Engineering students, non-traditional mathematics background	Bridging course, drop-in, workshops, & resources during the semester	Institution/ MSS data, Other (written student reflection + feedback)	Demographics, Diagnostic, Institution attainment, Pre-Institution attainment, Qual, Retention, Usage	n=54 users (2003-05) n=17 (2003) + 32 (2004) students, n=11 + 15 users	Implied institution/MSS records data collection.	Descriptive statistics, Graphs, Qual method not given	2003-05: Additional MSS helps non-traditional mathematics background, less well prepared students, to pass their 1st year mathematics modules but this effect does not appear to carry through to second year. Less well prepared but frequent users over the year tend to pass their mathematics module, less well prepared non-users or brief users tend to fail. Positive student feedback: more confidence in using MSS. 2003 (2004): 1 (4) attendee who used further support and 1 (4) attendee who did not use further support failed vs 1 (4) non-attendee who used further support and 2 (2) non-attendees who did use further support. 0 (2) attendees left the Bachelors, 1 (4) attendee failed the Bachelors, 5 (5) graduated, 1 (0) failed the masters and 4 (2) graduated from the masters. In 2004 3/13 attendees graduated in the expected year while 25/33 non attendees graduated on time.
37	Engineering students	Appointments or drop-in individual learning plans after diagnostics	Institution/ MSS data	Diagnostic, Institution attainment, Usage	n=20,371 students (2188 users)	MSS attendance data & module results collection not specified; diagnostic described.	Descriptive statistics, Chi-squared test, t-test, Graphs	92% of users pass compared to 88% of non-users this is sig. (p<0.01) by chi-squared test, mean module percentage of users 60.07% is sig. higher than non-users 56.06% (p=0.01) by t-test.

38	All MSS users	Mathematics Learning Centre (services not described)	Survey (based on IMAES instrument and the IMLSN evaluation survey)	Affective (attitude towards mathematics), Demographics, Pre-Institution attainment, Qual	n=124 students	Unclear how sampling was conducted; questionnaire had Cronbach's alpha=0.652; Pilot study occurred.	Descriptive statistics, Graphs, Cronbach's alpha, Qual theme identification	Impact themes: Teaching Strategies (positive, better than lecturers, similar to school), Greater Understanding, Extra Help (MSS helpful especially drop-in, prevented drop-outs), Student Attitude (more confident, less anxious, mathematics is easier/interesting/useful). 12 of 124 students considered dropping out & 8 said MSS had influenced them to stay. 92% of users gained increased mathematical confidence, 64% had changed opinion of mathematics, 43% changed study habits.
39	Engineering students from University of Sheffield (UoS) and Robert Gordon University (RGU), Computing students from RGU	1-1 tuition, diagnostic testing and follow-up, workshops, exam revision, online and paper resources, self-help groups, teaching logs	Institution/ MSS data, Pre- & post-skills assessment, Surveys	Affective (approaches to studying), Diagnostic, Institution attainment, Pre-Institution attainment, Usage	n=1,028 RGU students + 2,040 UoS students =3,068 students, n=117 (RGU) + 212 (UoS) MSS users	All data collection described in detail; low response rate for survey; all attitude data is from institution records.	Descriptive statistics, t-test, Multivariate ANOVA, Graphs, Regression analysis, Chi-squared test, Cohen's d (factor analysis and Cronbach alpha for attitudes survey)	At RGU users had sig. better pass rates in 1 2nd year module, not sig. better rates in 2 1st year modules & sig. worse rates in a 1st year module. At UoS users did worse or the same as non-users in pass rates with 2 1st year modules & 1 2nd year module sig. MSS decreased the gap between entry mathematics grades/diagnostic results & final grades in 2 of the 3 1st year RGU modules and all 4 of the 1st year UoS modules. Chi-squared tests showed sig. better pass rates for users with all RGU module results combined and 2nd year results combined (not combined 1st year results). At both universities those who only used MSS in 1st year performed better than those who used MSS in 1st & 2nd year. A model built to predict non- users' 1st year module result using entry qualifications and diagnostic results was used to predict the MSS users and the actual marks were greater than predicted marks with a medium to large effect size with best outcome for 2-5 visits.
40	Students from service mathematics courses	Individual or small-group sessions, workshops, drop-in sessions	Surveys	Affective (confidence), Course, Demographics, Institution attainment, Pre-Institution attainment, Qual, Usage	n=83 surveys	p-value correction for multiple tests not addressed; extensive section in paper addressing issues with data collection/problems with project.	Descriptive statistics, Paired sample t-tests, Graphs, Pearson's correlation analysis, No qual method given	Sig. increase in students' overall confidence, increase in confidence post individual sessions; moderate sig. correlation (r=0.61) between students' overall confidence (post support) and confidence in applying mathematics in their chosen profession; no sig between faculty and overall confidence (beginning or end of semester); no sig. between gender and overall confidence at beginning of semester but sig. at end of semester with males having higher confidence; no sig. between overall confidence and subject result

41	Two large, and four small populations of mainly mathematics students	MSS centres, serving 5-13 courses, 1 serves any mathematics question	Institution/ MSS data, Surveys	Institution attainment, MSC features, Usage	n=6 universities	6 of a 10 university convenience sample; respondent validation was employed.	Graphs, Multiple regression, Deductive thematic analysis based on Lee and Nowell (2015) theoretical framework	Regression models controlling for high school mathematics GPA and standardized test scores, for each visit to the centre students' final grades are predicted to increase: 0.015 grade points (R^2=0.186) one institution & 0.035 grade points (R^2=0.257) for another. 3rd institution had no sig. effect but model didn't include all users just 13 courses. 4th institution's student surveys had positive feedback re active learning; & motivating, encouraging, helpful tutors.
42	27 level 1 or 2 mathematics or statistics modules	MSS centre	Institution/ MSS data	Course, Institution attainment, Pre-Institution attainment, Usage	n=12,163 students	All data from MSS or institution records; correlation type not provided.	Moderation analysis, Graphs, Correlation, Descriptive statistics, Simple slope analysis	Model: university mathematics attainment as response, LC result as predictor, & number of MSS visits as moderator variables. More visits has a sig. impact on the relationship between LC mathematics grades and university maths grades. Students with lower secondary school mathematics backgrounds gain greater benefit from MSS use than their higher-achieving peers.
43	Students in 1st year undergrad mathematics courses	Drop-in centre	Institution/ MSS data	Course, Demographics, Institution attainment, Usage	n=657 students	Have waiver to analyse whole cohort data; considered statistical power of small sample size.	Descriptive statistics, t-test, Linear & logistic regression, Chi-squared test	Users scored on average 9.1 percentage points higher in their final exams when controlling for different courses (p=0.001); at-risk students were unlikely to seek additional MSS; at-risk users scored on average 11 percentage points higher on their final exam (p=0.47) & were more likely to pass (p=0.223).
44	Mathematics students across 10 universities	10 mathematics tutoring centres	Institution/ MSS data	Institution attainment, MSC features, Pre-institution attainment, Usage	n=26,750 students total (9%-68% users)	All data from MSS or institution records; missing data removed.	Descriptive statistics, Multiple linear regression, Graphs	Multiple linear regression predicted mathematics course letter grade point with number of visits, high school GPA, & SAT or ACT (standardised USA college admissions tests). The change in grade per 1 visit was positive in 6 centres with 5 sig. higher & negative in 4 centres with 2 sig. lower.
45	Calculus II students (MSS users)	Drop-in centre	Institution/ MSS data	Demographics, Institution attainment, Pre-institution attainment, Usage	n=683 students	Implied institution data collection; outliers explicitly treated.	Logistic regression, Cook's Distance	Regression with 16 variables controlling for student motivation and mathematical ability had accuracy of 88.14% or 91.35% when 47 observations removed using Cook's Distance and sig. positive relationship between MSS use and students' grades. Estimated that MSS helped 37 students pass.

46	Students taking College Algebra	1-1 support: tutoring, online resources, goal setting	Institution/ MSS data, Interviews, Other (goal setting, feedback)	Course, Qual, Qual - tutor/faculty, Usage	n=15 students	Data collected from students, faculty and MSS records by researcher.	Descriptive statistics, No qual method given	Increased grades and confidence; Students reported better study skills, time management, and overall more positive attitudes.
47	Calculus I students	Drop-in centre	Institution/ MSS data	Demographics, Institution attainment, Pre-Institution attainment, Usage	n=640 students	Implied institution/ MSS records data collection; missing data strategy discussed.	Descriptive statistics, Pearson correlation, Linear & multiple regression, Breusch-Pagan test	Number of visits sig. in linear regression predicting grade with R^2=0.05, & in multiple regression with positive co-efficient, partial R^2=0.06 & tolerance 0.97, multiple regression model was sig. & R^2=0.345. Interaction term between high school GPA & visits wasn't sig. with partial R^2=0.01 & a negative coefficient suggesting lower GPA student visits result in larger increase in course grade than those with higher GPA.
48	All MSS workshop attendees (including Science, Computing, Engineering students)	Workshops	Institution/ MSS data	Course, Institution attainment, Pre-Institution attainment, Usage	n=12,281 students (3,168 users)	All data from MSS or institution records.	Descriptive statistics, Pearson's Chi-squared test, two-way ANOVA, Tukey HSD, Multiple linear regression, Graphs	Sig. relationship (chi-squared) between workshop use and grades. MSS use, mathematical background & the interaction between them are associated with sig. diff. in marks (ANOVA). Users performed sig. higher than non-users, users with a Higher background performed sig. better than other users and users with Elementary background preformed sig. worse. Multiple linear regression: sig. coefficient for proportional MSS use, and many (not all) sig. coefficients for mathematical background categories and interaction terms. MSS use also sig. in model including discipline.
49	Differential Calculus students unprepared for university	Bridging course	Institution/ MSS data	Course, Institution attainment, Pre-Institution attainment, Retention, Usage	n=200 ('12) + 196 ('13) students, N= 81 ('12) +78 ('13) users	All data from MSS or institution records.	Descriptive statistics, Fisher's exact test, t-test, Graphs	Sig. association (Fisher) between usage and lower withdrawal rate. Failure rates and usage: sig. by Fisher in 2012 and not sig. in 2013. No sig. diff. in either year between failure rates of users and those who did not need MSS. Users had sig. higher (t-test) final marks than non-users who needed MSS students but sig. lower than students who did not need MSS.

50	1st year service mathematics students	Drop-in centre, exam revision & diagnostic testing	Institution/ MSS data, Interviews, Surveys	Diagnostic, Institution attainment, Likert (tutor behaviour, benefit of MSS), Pre-Institution attainment, Retention, Usage	n=161 users responded n=811 (04/05)+826 (05/06) target students, n=80 (04/05) + 161 (05/06) 'at risk'	Survey's response rate, design & distribution; design & number of interviews; participant recruitment; source of attainment & usage records all not explicitly given.	Descriptive statistics, No qual method supplied	52% of respondents strongly agree, 39% agree, 9% are neutral, 0% disagree and 0% strongly disagree with the statement ' I have benefited from using [MSS]' and 45% strongly agree, 38% agree, 13% were neutral, 3% disagree, and 1 % strongly disagree with '[MSS] contributes significantly to my maths learning'. Interviews indicated a positive opinion of MSS. The pass rate for target student users was 79% in 04/05 and 74% in 05/06 compared to the pass rate of target student non users of 76% and 68%. The pass rate of at-risk student users was 53% in 04/05 and 60% in 05/06 compared to at-risk non-users of 25% and 49%.
51	All MSS users with a focus on Engineering students	Drop-in sessions (other support available)	Surveys	Likert (usefulness), Usage	n=27 (2015/16) +19 (2016/17)	Survey distributed at end of drop-in sessions in 1 week; unclear survey design; response rate not provided.	Descriptive statistics, t-test, F-test, Pooled estimate of Bernoulli parameter	78% of students in 2015/16 said the drop-in sessions were always useful, while 81% of the students in 2016/17 thought the drop-in sessions were always useful and beneficial.
52	All MSS users with Engineering and/or Physics focus	Drop-in centres, small group teaching ('at-risk' students)	Focus groups, Institution/ MSS data, Interviews, Surveys	Diagnostic, Institution attainment, Qual, Usage	n=793 students, n=11 modules n=29 users interviews	Attendance data is via swipe card; all other data collected by researcher through interviews.	Descriptive statistics, Chi-squared test, Linear & multiple regression, Graphs, Interview analysis: categorisation	Linear model: Module mark = 0.9216(MSS visits)+56.367 has R^2=0.0149 for visitors and non-visitors, Module mark = 0.7855(MSS visits) +57.516 has R^2=0.0363 for visitors only and is sig. MSS use sig. in multiple regression model predicting module mark with diagnostic results, attendance rate and MSS visits with R^2=0.267. Users interviewed had positive productive visits to MSC which reassured & motivated them and improved their mathematical confidence. All users interviewed said the MSS had a positive impact on their mathematics learning and wider learning.
53	1st year Bioscience from 7 UK institutions	MathTutor, BioMathTut or paper & e-learning	Pre- & post-skills assessment	Institution attainment, Usage	n=287 for test 1, n=89 for test 2 (4 courses)	Manual examination of student scripts.	Descriptive statistics, ANOVA	No sig. diff. in performance between any of the groups assigned different learning resources (including the control) in either the first or second test.

54	Nursing and midwifery students	Intervention 1: 1-1 & small group MSS Intervention 2: workshop, big group drop-in sessions	Institution/ MSS data, Pre- & post-skills assessment	Diagnostic, Usage	Intervention 1: n=176 students n=11 users Intervention 2: n=240 students, n=35 users	Implied institution/ MSS records data collection.	Descriptive statistics, Graphs, ANOVA, Effect size, Paired sample t-test, Shapiro Wilk test for normality, Welch, Kruskal-Wallis, & Wilcoxon signed rank tests.	Intervention 1: Sig. increase in mean scores in retest for the users, non-users & whole group (t-test & Wilcoxon signed rank test) with large effect (0.731) for users & medium effect (0.385) for whole group. Within-between ANOVA showed the retest opportunity was a sig. main effect with medium effect (0.36) but between subjects' effect for MSS was not sig. Intervention 2: Only 1 low-scorer user, 6 among non-users. 4 groups (different MSS used including none) different in size etc. ANOVA & Kruskal-Wallis test show no sig. diff. between group means, Welch test shows sig. diff. -potential type I error, no conclusions.
55	Computing, Engineering & Built Environmen t students	MSS team led targeted timetabled lectures	Institution/ MSS data	Course, Institution attainment, Usage	n=4,690 students, n=47 modules	MSS attendance from swipe card system; unclear collection of attainment data.	Descriptive statistics, Graphs	Averaging over 47 modules and 5 years, users had average mark of 51%, non-users 53%. MSS users had higher average marks in 39 of the modules.

Appendix D: Scoping literature review MSS formats and data sources

The percentages in the Table D1 are the percentage of the overall number of included publications with the MSS format listed that used the listed data source, for example, 50% of the 20 publications that studied bridging courses used institution or MSS records. The numbers in brackets in the column and row names are the total number of publications with that MSS format or data source included.

Table D1: Data sources and MSS formats compared by percentage of included publications about an MSS format that used each data source.

MSS Format\Data Source	Focus Groups (11)	Institution or MSS Records (80)	Interviews (17)	Not Stated (9)	Other (21)	Pre/post Skills Test (14)	Surveys (90)
Bridging Course (20)	0 (0%)	10 (50%)	0 (0%)	1 (5%)	5 (25%)	5 (25%)	13 (65%)
Drop-in Sessions (64)	6 (9%)	38 (59%)	8 (13%)	2 (3%)	7 (11%)	3 (5%)	42 (66%)
MSC (19)	2 (11%)	14 (74%)	2 (11%)	0 (0%)	3 (16%)	0 (0%)	8 (42%)
Online Communication (11)	0 (0%)	4 (36%)	3 (27%)	0 (0%)	0 (0%)	1 (9%)	7 (64%)
Online Resources (36)	5 (14%)	19 (53%)	4 (11%)	2 (6%)	7 (19%)	6 (17%)	27 (75%)
Peer Tutoring (2)	2 (100%)	1 (50%)	1 (50%)	0 (0%)	2 (100%)	0 (0%)	1 (50%)
Tutorials (20)	3 (15%)	14 (70%)	4 (20%)	0 (0%)	3 (15%)	2 (10%)	13 (65%)
Paper Resources (18)	3 (17%)	8 (44%)	2 (11%)	3 (17%)	2 (11%)	2 (11%)	13 (72%)
Workshops (29)	0 (0%)	12 (41%)	3 (10%)	1 (3%)	6 (21%)	2 (7%)	17 (59%)
Appointments (21)	2 (10%)	10 (48%)	3 (14%)	3 (14%)	4 (19%)	1 (5%)	14 (67%)

Appendix E: Online MSS interview questions

For students:

1. Having read the **plain language statement** do you agree to take part in this study?
2. Could you tell me a little about your experience of online learning mathematics since last March?
    a. What were the challenges?
    b. What were the benefits/affordances?
    c. What are the main differences for you between online and face-to-face learning?
3. Is there anything about the subject of maths specifically that makes it more or less difficult to learn online as compared to other subjects?
4. Turning now to your experience of receiving support online in your maths and stats study, how would you describe the experience?
    a. How frequently have you used support services?
    b. What type of services have you used?
    c. Has the way you access support changed since COVID-19?
    d. If so, why?
5. Have you received support in any subjects other than maths or stats?
    a. If so, how does the support you have received in maths and stats compare to the support you have received in these other subjects?
6. Do you usually access support individually or in a group?
7. Has the support made you feel more connected to your fellow students, teachers or the university more generally?
8. Where else have you gone for help (if not a dedicated learning support service)?
9. Tell us about your interactions with support staff online:
    a. Is it easy or difficult to communicate with them?
    b. Do they make you feel comfortable and ready to learn?
    c. Are they usually successful in helping you with your problems or questions?
10. If you have received both online and face-to-face support in maths and stats, could you tell me about the differences between the two?
    a. When you seek help from a teacher because you don't understand a maths concept or solution method, for example, is it easier or more difficult to discuss your issues with them online or face-to-face?
    b. Do you interact with other students differently online vs face-to-face?
    c. Are you more comfortable receiving support online vs face-to-face?

    d. Are you more confident in seeking help online vs face-to-face?

11. Has receiving support online changed your attitude to the subject in any way?
    a. Do you have a more or less positive attitude towards the subject now?
    b. If your future subject choices were flexible, would you wish to study more or less university maths in the future?
12. Are there any elements of online support that you prefer and would not want to lose upon resumption of "normal" arrangements (post COVID-19)?
    a. What about the opposite: are there any elements you do not prefer?

For tutors:

1. Having read the **plain language statement** do you agree to take part in this study?
2. Could you tell me a little about your experience of online teaching mathematics since last March?
    a. What were the challenges?
    b. What were the benefits?
    c. What are the main differences for you between online and face-to-face teaching?
3. Is there anything about the subject of maths specifically that makes it more or less difficult to teach online as compared to other subjects?
4. Turning now to your experience of providing maths and stats support online, how would you describe the experience?
    a. How frequently were or are you providing support services online?
    b. What type of services have you provided?
    c. Has the way you provide support changed since COVID-19?
    d. If so, why?
5. How would you describe your interactions with your fellow tutors online?
6. Tell us about your interaction with support users (students) online:
    a. Is it easy or difficult to communicate with them?
    b. Are you usually successful in helping them with their problems or questions?
7. If you have provided both online and face-to-face support in maths and stats, could you tell me about the differences between the two?
    a. When you are speaking to a student, is it easier or more difficult to discuss their issues with them online or face-to-face?
    b. Do you interact with other teachers differently online vs face-to-face?
    c. Are you more comfortable giving support online vs face-to-face?
    d. Are you more confident in giving help online vs face-to-face?

8. Has giving support online changed your attitude to the subject in any way?
    a. Do you have a more or less positive attitude towards teaching the subject now?
    b. Has this affected how you think about your future in teaching maths and stats?
9. Are there any elements of online support that you prefer and would not want to lose upon resumption of "normal" arrangements (post COVID-19)?
    a. What about the opposite: are there any elements you do not prefer?

Appendix F: Online MSS plain language statement

Plain Language Statement - Information Letter

November 3rd 2020

You are being invited to take part in research on the changes to mathematics and statistics support in higher education since the beginning of the Covid-19 pandemic.
The **research team** are: PhD student Claire Mullen (University College Dublin, Ireland), who is leading this research alongside Assistant Professor Anthony Cronin (Lecturer and Mathematics Support Centre manager, University College Dublin), Dr Jim Pettigrew (Lecturer at the Mathematics Education and Support Hub (MESH) in Western Sydney University, Australia), Don Shearman (Learning Advisor, MESH, Western Sydney University) and Associate Professor Leanne Rylands (Head of MESH, Western Sydney University).

Before you decide to take part it is important you understand why this research is being conducted and what it will involve. Please take time to read the following information carefully.

Purpose of the Study
The purpose of this international study is to determine the scope and perspectives of both students and tutors on how the mitigation strategies resulting from Covid-19 have resulted in interventions or adaptive techniques for offering mathematics and statistics support. We are interested to see how institutions are offering online support, whether, and in what forms they plan to continue online support after the pandemic. We are also interested in the student perspective of mathematics and statistics support so that we may aim to improve this going forward.

What will the study involve?
The study will involve tutors of mathematics and statistics support and, separately, students of mathematics and statistics support giving their insights via focus groups/interviews into the move to online mathematics and statistics support enforced by the Covid-19 pandemic.

Who has approved this study?
This study has been approved by both the UCD Office of Research Ethics and the Western Sydney University Human Research Ethics Committee.

Why have you been asked to take part?
You are invited to participate in this study because you are either a mathematics and statistics support tutor or a student who has used mathematics and statistics support at an institution offering mathematics and statistics support.

Do you have to take part?
No – it is entirely up to you. If you do decide to take part, please keep this Information Sheet to show that you understand your rights in relation to the research, and that you are happy to participate. Please note down the time at which you participated and provide this to the lead researcher if you seek to withdraw from the study at a later date. You are free to withdraw your information from the project data set at any time until the data are destroyed in July 2025. You should note that your data may be used in the production of formal research outputs (e.g. journal articles, conference papers, theses and reports) prior to this date and so you are advised to contact the university at the earliest opportunity should you wish to withdraw from the study. To withdraw, please contact the lead

researcher (Claire Mullen, claire.mullen@ucdconnect.ie). You do not need to give a reason. A decision to withdraw, or not to take part, will not affect you in any way.

If I choose to take part what information will be collected?
You will be asked a number of questions regarding your mathematics and statistics support provision/tuition to help us answer our research questions:

1. What are the issues affecting the learning and teaching of university mathematics in a wholly online learning support environment in the covid era?
2. What impact does the switch to wholly online learning, teaching and support of university mathematics have on student attitudes to their study, particularly as they relate to retention, transition and progression?

The interview/focus group will take place online at a time that is convenient to you. You should feel comfortable to respond to the questions honestly and you will not be identifiable from the data you provide. The interview/focus group should take around 20 minutes to complete.

Will your participation in the study be kept confidential?
Data Protection and Confidentiality
Your data will be processed in accordance with the General Data Protection Regulation 2016 (GDPR) and the Data Protection Act 2018. All information collected about you will be kept strictly confidential. Unless they are fully anonymised in our records, your data will be referred to by a unique participant number rather than by name. If you consent to being audio recorded, all recordings will be destroyed once they have been transcribed. Your data will only be viewed by the researcher/research team. All electronic data will be stored on a password-protected computer file on the lead researcher's Google Drive. Your consent information will be kept separately from your responses in order to minimise risk in the event of a data breach. The lead researcher will take responsibility for data destruction and all collected data will be destroyed on or before 31st July 2025.

What will happen to the information that you give?
Data Protection Rights
University College Dublin is a Data Controller for the information you provide. You have the right to access information held about you. Your right of access can be exercised in accordance with the General Data Protection Regulation and the Data Protection Act 2018. You also have other rights including rights of correction, erasure, objection, and data portability. For more details, including the right to lodge a complaint, questions, comments or requests about your personal data please email the University Data Protection Office at gdpr@ucd.ie.

What will happen with the results of this study?
The results of this study may be summarised in published articles, reports and presentations. Quotes or key findings will always be made anonymous in any formal outputs unless we have your prior and explicit written permission to attribute them to you by name.

What are the possible disadvantages/risks of taking part?
This study has been reviewed and approved through University College Dublin's formal research ethics procedure. We understand that discussing the impact Covid-19 has had on our lives can be distressing for some people. However, in this study we are only focusing on the nature of maths and

stats support as a result of restrictions introduced to limit the spread of the COVID 19 Pandemic and not on any issues relating directly to COVID 19 itself. Participants who experience distress can withdraw at any time simply by requesting this from the lead researcher (data will not be saved), or (if the study has been completed and answers saved) by contacting the lead researcher (Claire Mullen).

What are the possible benefits of taking part?
By sharing your experiences with us, you will be helping the research team to better understand the impact the strategies used to mitigate the spread of Covid-19 has had on mathematics and statistics support provisions.

What if there is a problem?
Please contact the lead researcher in the first instance or if you feel uncomfortable with that please contact Anthony Cronin at + 353 (0)87 768 7316 or via email at anthony.cronin@ucd.ie.

Any further queries?
For more details, including the right to lodge a complaint, questions, comments or requests about your personal data please email the:
UCD Office Of Research Ethics at research.ethics@ucd.ie or the
WSU Office of Research Ethics at humanethics@westernsydney.edu.au

University Data Protection Office at gdpr@ucd.ie

Appendix G: Optimising the blend in MSS survey instrument

There were six surveys, three for UCD and three for Western Sydney University, with one for students who have used both online and in-person MSS, those who used online only and those who used in-person only. The “both” version for UCD is presented here as the differences between the surveys by format used is that students were asked to rate only online or only in-person instead of both, and the differences between the UCD and WSU versions are the time options for question 7 and the exchange of the phrase “Maths Support Centre (MSC)” for “Mathematics Education Support Hub (MESH)”.

1. How do you rate the quality of the in-person (on campus) and online help you have received from the Maths Support Centre (MSC)?

In-person	**Online**
Very good	Very good
Good	Good
Neutral	Neutral
Poor	Poor
Very poor	Very poor

2. Rate the quality of each of the following aspects of mathematics and/or statistics support for both in-person and online help.

   Options: Very good; Good; Neutral; Poor; Very poor; N/A

	In-person	**Online**
Tutoring		
One-on-one attention from tutor		
Connection/interactivity with peers		
Learning environment (comfort, noise, people distractions, etc.)		
Convenience of times and locations		
Usefulness of learning resources provided		
Access to required technology		
Ease of verbally describing mathematical or statistical problems		
Ease of writing mathematical or statistical notation		
Clarity of how the service operates		

3. Rate the importance of each aspect of mathematics and/or statistics support to you.

Options: 1=Not important; 2=Less important; 3=Moderately important; 4=Important; 5=Very important.

Quality of tutoring	
Quality of one-on-one attention from tutor	
Quality of connection/interactivity with peers	
Quality of learning environment (comfort, noise, people distractions, etc.)	
Convenience of times and locations	
Usefulness of learning resources provided	
Access to required technology	
Ease of verbally describing mathematical or statistical problems	
Ease of writing mathematical or statistical notation	
Clarity of how the service operates	

4. For each situation, pick which mode of support you would prefer to use:

	In-person	**Online**
You are on campus and have a quick question		
You are on campus and have a complex question		
You are at home and have a quick question		
You are at home and have a complex question		
You have an assessment due soon		
You want to access support with friends		
You want help from a particular tutor		
You want help with use of mathematics or statistics software/app/computer program		

5. In terms of working through your mathematical or statistical problems (with a MSC tutor) I am…

   More likely to stay until I understand it when in-person

   No real difference

   More likely to stay until I understand it when online

6. Given the choice, how would you access mathematics and statistics at UCD in the future?

   In-person only

In-person mostly

A mixture of both depending on what suits me best

Online mostly

Online only

The MSC is no longer available to me

7. Pick the one most important factor that would make online mathematics and statistics support more attractive to you in the future:

   Better broadband/Wi-Fi connection

   Access to tablet and electronic pen etc. to write mathematics or statistics

   Clearer guidance on how it operates

   Timetable suitability

   Increased travel time to campus

   Suitable learning/working environment to access support

   Opportunity to be with friends (e.g. in breakout rooms)

   Guarantee of anonymity

   Other (if chosen, asked: please give details)

8. Pick the one most important factor that would make in-person mathematics and statistics support more attractive to you in the future:

   Covid guarantees (Vaccinated tutors/students, social distancing, mask wearing, sanitiser…)

   Clearer guidance on how it operates

   Timetable suitability

   More opportunity to be physically present with friends

   Less distracting learning environment

   Decreased travel time to campus

   In-person support having a less formal atmosphere

   Other (if chosen, asked: please give details)

9. Identify the one most important factor that would improve your experience of online mathematics and statistics support.:

   Better broadband/Wi-Fi connection

   Access to tablet and electronic pen etc. to write mathematics or statistics

   Clearer guidance on how it operates

Timetable suitability

Increased travel time to campus

Suitable learning/working environment to access support

Opportunity to be with friends (e.g. in breakout rooms)

Guarantee of anonymity

Other (if chosen, asked: please give details)

10. Identify the one most important factor that would improve your experience of in-person mathematics and statistics support:

    Covid guarantees (Vaccinated tutors/students, social distancing, mask wearing, sanitiser…)

    Clearer guidance on how it operates

    Timetable suitability

    More opportunity to be physically present with friends

    Less distracting learning environment

    Decreased travel time to campus

    In-person support having a less formal atmosphere

    Other (if chosen, asked: please give details)

11. Given the choice of times for online mathematics and statistics support going forward, please rank the following options in order of preference (with 1 for first preference, 2 for the second preference and so on).

    5pm – 7pm Monday to Friday

    6pm – 8pm Monday to Friday

    7pm – 9pm Monday to Friday

    8pm – 10pm Monday to Friday

12. I would use online mathematics and statistics support if it was available on Saturdays.

    Yes

    No

13. I would like the option of accessing online support during regular 10am-5pm hours also (even if on campus).

    Yes

    No

14. Are there any issues of accessibility, equity, diversity or inclusion that you would like to see addressed in either the online or in-person mathematics and statistics support services? Please explain.

Appendix H: Optimising the blend in MSS plain language statement

Optimising the blend in mathematics support - Plain Language Statement

You are being invited to take part in the research project titled "Optimising Maths Support in the New Normal". This research is being conducted by Claire Mullen, PhD student in the UCD School of Mathematics and Statistics, and Dr Anthony Cronin, Assistant Professor at the UCD School of Mathematics and Statistics with colleagues from Western Sydney University. Before you decide to take part it is important you understand why the research is being conducted and what it will involve.

What is this research about?

This study is focused on: implementing best practice in hybrid mathematics support. The study involves an anonymous survey on your previous and future experience of accessing maths support at UCD online and/or in person.

How will my data be used?

The anonymous results from surveys will be used to inform future service of maths support at UCD.

Why have you been invited to take part?

You are invited to participate in this study because you have either utilised the online or on-campus maths support centre at UCD.

What are the benefits of taking part?

By participating in this research you may improve operations of the UCD maths support centre.

Do I have to take part?

No - participation is voluntary.

Are there any risks associated with taking part?

There are no foreseeable risks associated with taking part in the anonymous study.

Can I change my mind and withdraw from the study?

Yes of course, if you do decide not to take part then you may ignore the rest of this statement and simply close the browser tab. If you respond to the survey and click submit we will take that as your consent for your anonymous responses to be recorded and analysed for research purposes.

How will your privacy be protected?

Your data will be processed in accordance with the General Data Protection Regulation 2016 (GDPR) and the Data Protection Act 2018. All the anonymous information collected via your responses will be kept strictly confidential and secure. Your data will only be viewed by the research team. All electronic data will be stored on a password-protected computer file. Following the completion of the study all data relating to the survey will be archived and/or destroyed.

What will happen with the results of this study?

You can contact one of the research team who will be able to speak to you about the results of the study. The results of this study may be summarised in published articles, theses, reports and presentations.

Contact Details

This project has been approved by the Human Research Ethics Committee (HREC) of University College Dublin. If you are unhappy with any aspect of this research or have any questions about your participation, please contact either Claire Mullen or Dr Anthony Cronin using the details below. If you have any concerns or complaints about the conduct of this research project, which you do not wish to discuss with the research team, you should contact the HREC team at hrec@ucd.ie

Claire Mullen: claire.mullen@ucdconnect.ie
Anthony Cronin: anthony.cronin@ucd.ie
Phone: 01 716 7536 or 087 768 7316

Appendix I: Optimising the blend of MSS mean ratings

Figure I1 shows the mean rating and standard deviation of each aspect listed, separated by the three survey groups as there were no significant differences in the ratings between the UCD and WSU survey groups. Figure I2 shows the mean rating and standard deviation separated by institution and survey group for the aspects where there were significant differences between the WSU and UCD respondents within a survey group. Students in the Both survey group rated both online and in-person MSS separately for each aspect. N/As were separated and the percentage of respondents in the group who chose N/A for an aspect and the total number of respondents, including N/As, are reported in the brackets. The colours highlight how far a rating is from the overall average rating with the deepest blue being the lowest rating, the deepest orange showing the highest rating and white representing the 50th percentile rating.

Aspect	B rating Online	A rating Online	A rating In-person	C rating In-person
Quality of help	4.29 (SD=0.99, 0% N/As, N=55)	4.44 (SD=0.87, 0% N/As, N=41)	4.29 (SD=0.84, 0% N/As, N=103)	4.54 (SD=0.83, 0% N/As, N=128)
Clarity of how the service operates	4.49 (SD=0.81, 6% N/As, N=54)	4.23 (SD=1.10, 0% N/As, N=40)	4.28 (SD=0.84, 7% N/As, N=92)	4.36 (SD=0.79, 2% N/As, N=129)
Access to required technology	4.49 (SD=0.71, 8% N/As, N=53)	4.26 (SD=0.89, 5% N/As, N=40)	4.35 (SD=0.75, 10% N/As, N=91)	4.08 (SD=0.94, 17% N/As, N=129)
Ease of verbally describing mathematics	4.2 (SD=0.87, 6% N/As, N=54)	4.03 (SD=0.95, 0% N/As, N=40)	4.45 (SD=0.69, 6% N/As, N=99)	4.4 (SD=0.84, 2% N/As, N=130)
Ease of writing mathematics*	4.22 (SD=0.90, 6% N/As, N=54)	3.73 (SD=1.26, 0% N/As, N=40)	4.63 (SD=0.55, 5% N/As, N=98)	4.48 (SD=0.71, 4% N/As, N=129)
Quality of tutoring	4.31 (SD=0.98, 9% N/As, N=54)	4.32 (SD=0.91, 5% N/As, N=39)	4.29 (SD=0.90, 9% N/As, N=93)	4.54 (SD=0.78, 7% N/As, N=130)
Quality of one-on-one attention	4.13 (SD=0.94, 11% N/As, N=54)	4.39 (SD=0.99, 8% N/As, N=39)	4.11 (SD=1.10, 9% N/As, N=93)	4.44 (SD=0.93, 5% N/As, N=130)
Usefulness of learning resources	4.34 (SD=0.98, 2% N/As, N=54)	4.5 (SD=0.84, 0% N/As, N=40)	4.34 (SD=0.77, 6% N/As, N=95)	4.25 (SD=0.88, 6% N/As, N=130)
Quality of interactivity with peers*	3.7 (SD=1.07, 10% N/As, N=51)	3.03 (SD=1.22, 10% N/As, N=39)	4 (SD=1.04, 10% N/As, N=93)	4.1 (SD=0.95, 10% N/As, N=130)

Figure I1: Mean rating and standard deviation by survey group of the nine aspects that had no statistically significant differences between UCD and WSU responses within each survey group, where 5 is Very Good and 1 is Very Poor.

Aspect	UCD B rating Online	UCD A rating Online	UCD A rating In-person	UCD C rating In-person	WSU B rating Online	WSU A rating Online	WSU A rating In-person	WSU C rating In-person
Quality of learning environment*	4.08 (SD=1.16, 0% N/As, N=12)	4.27 (SD=1.12, 4% N/As, n=23)	4.05 (SD=0.84, 5% N/As, n=20)	4.6 (SD=0.71, 1% N/As, n=103)	4.11 (SD=1.08, 13% N/As, n=40)	4.53 (SD=0.52, 6% N/As, n=16)	4.09 (SD=1.22, 27% N/As, n=15)	3.84 (SD=1.14, 4% N/As, n=26)
Convenience of times and locations*	4.54 (SD=0.78, 0% N/As, n=13)	4.58 (SD=0.72, 0% N/As, n=24)	4.05 (SD=0.76, 5% N/As, n=21)	4.29 (SD=0.81, 1% N/As, n=104)	4.15 (SD=1.04, 3% N/As, n=40)	4.63 (SD=0.62, 0% N/As, n=16)	4 (SD=1.09, 27% N/As, n=15)	3.6 (SD=1.00, 4% N/As, n=26)

Figure I2: Mean rating and standard deviation by institution and survey group of the two aspects that had statistically significant differences between UCD and WSU responses within each survey group, where 5 is Very Good and 1 is Very Poor.

Figure I3 shows the mean rating and standard deviation of the importance of each aspect listed split into the three survey groups as there were no significant differences in the ratings between the UCD

Importance of:	A. Both	B. Online Only	C. In-person Only
Quality of learning environment	4.25 (SD=0.69, N=36)	4.45 (SD=0.73, N=51)	4.37 (SD=0.82, N=119)
Convenience of times and locations	4.31 (SD=0.90, N=35)	4.46 (SD=0.65, N=49)	4.15 (SD=0.69, N=117)
Clarity of how the service operates	4.31 (SD=0.78, N=32)	4.46 (SD=0.74, N=48)	4.15 (SD=0.97, N=112)
Access to required technology*	4.03 (SD=1.13, N=33)	4.45 (SD=0.74, N=49)	3.56 (SD=1.25, N=109)
Ease of verbally describing mathematics	4.58 (SD=0.60, N=38)	4.60 (SD=0.72, N=52)	4.64 (SD=0.62, N=121)
Ease of writing mathematics	4.50 (SD=0.60, N=38)	4.41 (SD=0.90, N=51)	4.49 (SD=0.81, N=119)
Quality of tutoring	4.74 (SD=0.45, N=42)	4.62 (SD=0.77, N=52)	4.75 (SD=0.62, N=125)
Quality of one-on-one attention	4.56 (SD=0.67, N=41)	4.45 (SD=0.90, N=47)	4.65 (SD=0.68, N=121)
Usefulness of learning resources*	4.33 (SD=0.86, N=36)	4.61 (SD=0.72, N=51)	4.12 (SD=1.01, N=115)
Quality of interactivity with peers	3.62 (SD=1.16, N=37)	3.64 (SD=1.18, N=44)	3.30 (SD=1.39, N=118)

Figure I3: Mean rating and standard deviation by survey group of the importance of the ten aspects where 5 is Very Important and 1 is Not Important.

and WSU survey groups. Students were given a five-point scale of 1 Not important to 5 Very important. The number of respondents is reported in the brackets. Again, the intensity of colour is proportional to the rating's percentile with the deepest blue being the lowest mean rating, the deepest orange showing the highest rating and white representing the 50th percentile rating.

Appendix J: MathsFit quiz

2020 version

Arithmetic and Trigonometry

1. What is $10 - 8 \div 2 + 9$?

   - ○ 10
   - ○ $\frac{2}{11}$
   - ○ 23
   - ➡ ◉ 15
   - ➡ (25 %) ○ I don't know.

2. What is $\frac{1}{2} - \frac{1}{3}$?

   - ➡ ◉ $\frac{1}{6}$
   - ○ $\frac{1}{3}$
   - ○ -1
   - ○ $\frac{1}{5}$
   - ➡ (25 %) ○ I don't know.

3. What is $\frac{2}{3} \times \frac{4}{5}$?

   - ○ $\frac{6}{8}$
   - ○ $\frac{8}{35}$
   - ➡ ◉ $\frac{8}{15}$
   - ○ $\frac{6}{15}$
   - ➡ (25 %) ○ I don't know.

What is $8^{\frac{1}{3}}$?

➡ ◉ 2

○ $\frac{8}{3}$

○ 512

○ 8.333

4. ➡ (25 %) ○ I don't know. Harder for engineers and science

Simplify $\frac{1}{3^{-2}} + 3^{-1} \times 3 - \left(9^{\frac{1}{2}} \div 3\right)$.

○ $6\frac{1}{6}$

○ $9\frac{1}{9}$

➡ ◉ 9

○ 3

5. ➡ (25 %) ○ I don't know.

Chris has just received her car driving licence and wants to buy her first car.

The table below shows the details of four cars she finds at a local car dealer.

Model	Alpha	Bolte	Castel	Dezal
Year	2003	2000	2001	1999
Advertised price (zeds)	4800	4450	4250	3990
Distance travelled (kilometres)	105 000	115 000	128 000	109 000
Engine capacity (litres)	1.79	1.796	1.82	1.783

Chris wants a car that meets **all** of these conditions:

1. The distance travelled is **not** higher than 120 000 kilometres.
2. It was made in 2000 or a later year.
3. The advertised price is not higher than 4500 zeds.

Which car meets Chris's conditions?

○ Alpha

➡ ◉ Bolte

○ Castel

○ Dezal

6. ➡ (25 %) ○ I don't know.

Which car's engine capacity is the smallest?

○ Alpha

○ Bolte

○ Castel

➡ ◉ Dezal

7. ➡ (25 %) ○ I don't know.

Chris will have to pay an extra 2.5% of the advertised cost of the car as taxes.

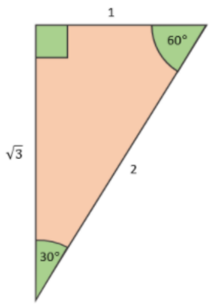
How much are the extra taxes for the Alpha?

- ◯ 1200
- ➡ ◉ 120
- ◯ 116
- ◯ 236

➡ (25 %) ◯ I don't know.

8.

For the following triangle, which fraction represents $\sin(30^{\circ})$?

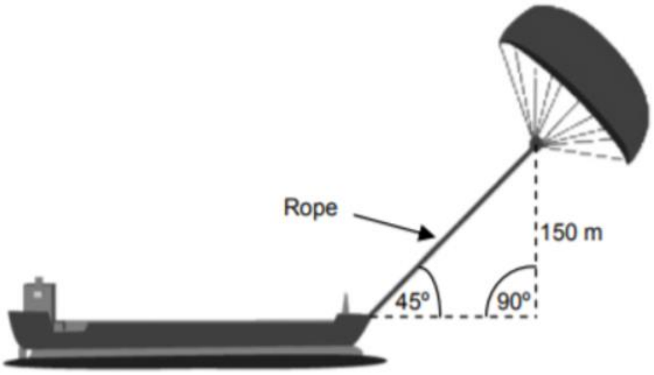


- ◯ $\frac{1}{\sqrt{3}}$
- ◯ $\frac{2}{\sqrt{3}}$
- ◯ $\frac{\sqrt{3}}{2}$
- ➡ ◉ $\frac{1}{2}$

➡ (25 %) ◯ I don't know.

9.

Approximately what is the length of the rope for the kite sail, in order to pull the ship at an angle of 45° and be at a vertical height of $150m$ as shown in the diagram below?



○ $173m$

➡ ◉ $212m$

○ $285m$

○ $300m$

10. ➡ (25 %) ○ I don't know.

Algebra

Solve the simultaneous equations

$$2x + y = 7$$
$$x + 2y = 5$$

If you are not sure of an answer you should enter IDK (meaning I don't know) in the relevant box.

1. $x =$ _______ (/3/, IDK) $y =$ _______ (/1/, IDK)

Simplify $\frac{3}{x} + \frac{5}{x+2}$

○ $\frac{8}{2x+2}$

○ $\frac{5x+6}{2x+2}$

○ $\frac{8x+2}{x^2+2x}$

➡ ◉ $\frac{8x+6}{x^2+2x}$

2. ➡ (25 %) ○ I don't know.

If the solutions to the quadratic equation $f(x) = 0$ are $x = 2$ and $x = -3$, what might $f(x)$ be?

- ◯ $x^2 + 5x + 6$
- ◯ $2x^2 + x - 6$
- ➡ ◉ $x^2 + x - 6$
- ◯ $x^2 + x + 6$

3. ➡ (25 %) ◯ I don't know.

Rearrange $v^2 = u^2 + 2as$ in terms of a.

- ◯ $a = (v^2 + u^2)(2s)$
- ➡ ◉ $a = \dfrac{v^2 - u^2}{2s}$
- ◯ $a = \dfrac{u^2 - v^2}{2s}$
- ◯ $a = \dfrac{v^2 - u^2}{s}$

4. ➡ (25 %) ◯ I don't know.

Simplify the expression $\dfrac{\left(x^{\frac{1}{2}}y\right)^2}{x^2}$.

- ◯ xy
- ◯ x^2y^2
- ➡ ◉ $x^{-1}y^2$
- ◯ $x^{-\frac{1}{2}}y$

5. ➡ (25 %) ◯ I don't know.

$(x^2 + x + 6)(x + 2)$ equals:

- ◯ $x^2 + 2x + 8$
- ◯ $x^3 + 2x^2 + 6x + 12$
- ➡ ◉ $x^3 + 3x^2 + 8x + 12$
- ◯ $x^3 + 2x + 12$

6. ➡ (25 %) ◯ I don't know.

Solve the inequality $-4 \leqslant 3x + 2 < 11$

➡ ◉ $-2 \leqslant x < 3$

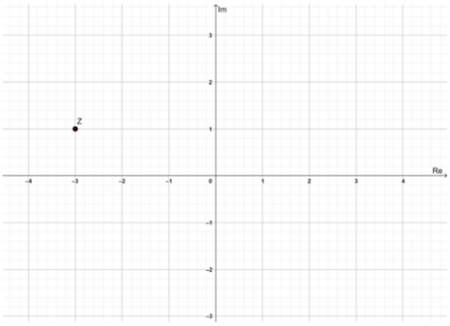
○ $-2 \leqslant x \leqslant 3$

○ $-\frac{2}{3} < x \leqslant \frac{13}{3}$

○ $-\frac{2}{3} \leqslant x < \frac{13}{3}$

7. ➡ (25 %) ○ I don't know.

A complex number z is shown in the following graph.
What is iz?



○ $-3 + i$

➡ ◉ $-1 - 3i$

○ $1 - 3i$

○ $3 - i$

8. ➡ (25 %) ○ I don't know.

Enter the roots of the equation
$x^3 + 2x^2 + x = 0$ in the boxes below.
They should be entered in ascending order.
If you are not sure of an answer you should enter
IDK (meaning I don't know) in the relevant box.

9. $x_1 =$ ________ (/-1/, IDK) $x_2 =$ ________ (/-1/, IDK) $x_3 =$ ________ (/0/, IDK)

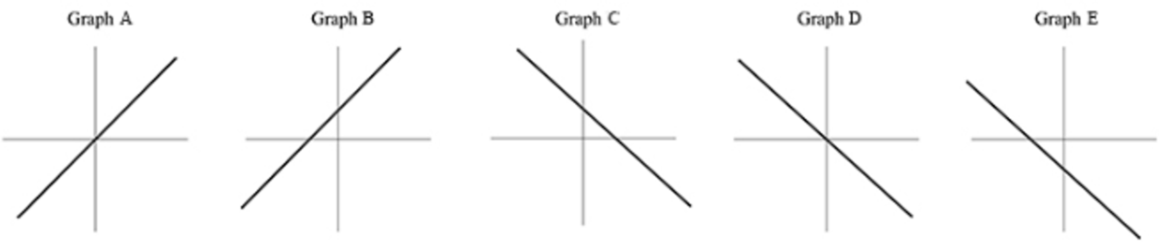
The roots of $x^2 + 5x - 7$ are

- ➡ ◉ $\frac{-5 \pm \sqrt{53}}{2}$
- ○ $\frac{-5 \pm \sqrt{-3}}{2}$
- ○ $\frac{5 \pm \sqrt{53}}{2}$
- ○ $\frac{5 \pm \sqrt{3}}{2}$

10. ➡ (25 %) ○ I don't know.

Functions and Calculus

Which of the following graphs could be that of $y = 3x + 4$?



- ○ *A*
- ➡ ◉ *B*
- ○ *C*
- ○ *D*
- ○ *E*

1. ➡ (25 %) ○ I don't know.

Evaluate $f(-2)$ if $f(x) = x^3 - 3x^2 + 6x - 17$.

- ○ -33
- ➡ ◉ -49
- ○ -25
- ○ -9

2. ➡ (25 %) ○ I don't know.

If $g(x) = -2x^2 + 5x - 7,$ for which x is $g(x) = -10$?
They should be entered in ascending order.
If you are not sure of an answer you should enter
IDK (meaning I don't know) in the relevant box.
The values of x should be

3. $x_1 =$ ________ (/-1/2/, IDK, /-0.5/, /-.5/) $x_2 =$ ________ (/3/, IDK)

What is the range (image) of the function
$h(x) = -3x + 10$ for $-2 \leqslant x < 5$?

- ○ $-5 \leqslant h(x) \leqslant 16$
- ○ $-5 < h(x) < 16$
- ➡ ◉ $-5 < h(x) \leqslant 16$
- ○ $-5 \leqslant h(x) < 16$

4. ➡ (25 %) ○ I don't know.

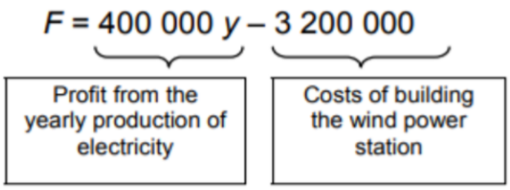
Is $y^2 = x + 3$ a function?

- ○ Yes
- ➡ ◉ No

5. ➡ (25 %) ○ I don't know.

Zedtown wants to estimate the costs and the profit that would be created by constructing a wind power station.

Zedtown's mayor proposes the following formula for estimating the financial gain, F zeds, over a number of years, y, if they build the E-82 model.



Based on the mayor's formula, what is the minimum number of years of operation required to cover the cost of construction of the wind power station?

- ○ 6 years
- ➡ ◉ 8 years
- ○ 10 years
- ○ 12 years

6. ➡ (25 %) ○ I don't know.

If $y = -2x^2 + 5,$ what is $\dfrac{dy}{dx}$?

- ➡ ◉ $-4x$
- ○ $2x + 5$
- ○ $-4x + 5$
- ○ $-2x$

7. ➡ (25 %) ○ I don't know.

Determine the first derivative (with respect to x) of
$f(x) = x^3 + 2x^2 - 7x + 4$.

○ $3x^2 + 4x - 7 + 4$

➡ ◉ $3x^2 + 4x - 7$

○ $x^2 + 2x - 7$

○ $\frac{x^4}{4} + \frac{2x^3}{3} - \frac{7x^2}{2} + 4x + c$

8. ➡ (25 %) ○ I don't know.

The derivative of a function is negative everywhere on the interval
$4 \leqslant x \leqslant 5$.
Where on the interval does the function have its maximum value?

➡ ◉ $x = 4$

○ $x = 5$

○ $x = 4.5$

○ There is no maximum.

9. ➡ (25 %) ○ I don't know.

A sofa factory produces n sofas per hour.
The cost of running the factory is $C(n) = n^2 - 16n + 400$.
How many sofas should the factory produce to keep
the costs to a minimum?

○ $\frac{16 \pm \sqrt{1344}}{2}$

○ 16

➡ ◉ 8

○ 4

10. ➡ (25 %) ○ I don't know.

2021 and 2022 quizzes

As the content of the 2021 and 2022 quizzes was the same the 2022 quiz questions are presented here, that is how they looked in Bolster Academy. The question order was random for each student and they only answered eight questions per section. The modules (A-E) which answered that question, as there were four versions of the quiz, are below each question. In total there were 16 different Arithmetic and Trigonometry questions, 9 Algebra questions, and 11 Functions and Calculus questions. Note, module C saw the Functions and Calculus question which gives the quadratic formula in their Algebra section.

Arithmetic and Trigonometry

Calculate $-\frac{4}{3} \times \frac{17}{12}$. Simplify the answer as much as possible.

$-\frac{4}{3} \times \frac{17}{12} =$ ....

Modules A, B, C

Calculate $32^{\frac{3}{5}}$ in two steps.
E.g. $8^{\frac{2}{3}} = 2^2 = 4$

$32^{\frac{3}{5}} =$ ....$^{3} =$ ....

Modules A, B, C, D, E

Simplify $\frac{1}{3^{-3}} + 3^{-1} \times 3 - \left(9^{\frac{1}{2}} \div 3^2\right)$.

a. $3^3 + 1 - \frac{1}{3^2}$

b. $\frac{1}{3^3} + 3^2 - 1$

c. $3^3 + \frac{1}{3^2} - \frac{1}{3}$

d. $3^3 + 1 - \frac{1}{3}$

Modules A, B, C, D, E

Ilja has just received their driving license and wants to buy their first car. The table below shows the details of four cars they find at a local car dealer.

Model	Tipo	Juke	Kuga	Stonic
Year	2011	2012	2013	2014
Advertised Price €	4400	5340	4140	5750
Distance travelled (kilometres)	121000	144000	132000	134000
Engine capacity (litres)	1.742	1.739	1.668	1.616

Ilja wants a car that meets **all** of the following conditions:

1. The distance travelled is lower than 137000 kilometres.
2. It was made in 2012 or a later year.
3. The advertised price is not higher than 4455 euros.

Which car meets Ilja's condition?

a. Tipo

b. Juke

c. Kuga

d. Stonic

Modules A, B, C,

Chin is also in the market for a new car. The table below shows the details of four cars they find at another car dealer.

Model	Alpha	Bolte	Castel	Dezal
Year	2011	2012	2013	2014
Advertised Price €	4400	5340	4140	5750
Distance travelled (kilometres)	121000	144000	132000	134000
Engine capacity (litres)	1.742	1.739	1.668	1.616

Which car has the largest engine capacity?

a. Alpha

b. Bolte

c. Castel

d. Dezal

Modules A, B

The table below shows again the details of the four cars they found at the other car dealer.

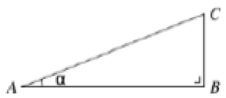
Model	Alpha	Bolte	Castel	Dezal
Year	2011	2012	2013	2014
Advertised Price €	4400	5340	4140	5750
Distance travelled (kilometres)	121000	144000	132000	134000
Engine capacity (litres)	1.742	1.739	1.668	1.616

Chin will have to pay an extra 10.2% of the advertised cost of the car they chose as taxes. How much are the extra taxes for the **Bolte**. Please give your answer correct to two decimal places.

€ ....

Modules A, B, C

Consider a triangle ABC with an angle α in vertex A and a right angle in vertex B as shown in the figure (not to scale). Also, $|AB| = 192$, $|BC| = 80$ and $|AC| = 208$.

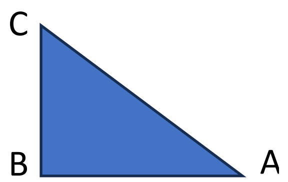


Calculate $\sin(\alpha)$. Simplify your answer as much as possible.

$\sin(\alpha) =$ ....

Modules A, C

In the figure below, we see the right-angled triangle ABC, with sides $AB = 4$, $AC = 5$, and unknown side BC.



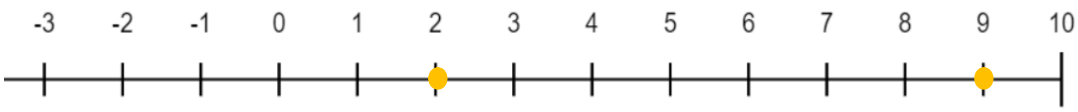
Calculate the length of the side BC. Give your answer in exact form, so as an integer or a simplified root.

$BC =$ ....

Module A

Drag and click on the orange dots until your answer represents the interval $5 \leq x < 8$.

Clicking on a dot changes the dot from an open to a closed circle and vice versa.

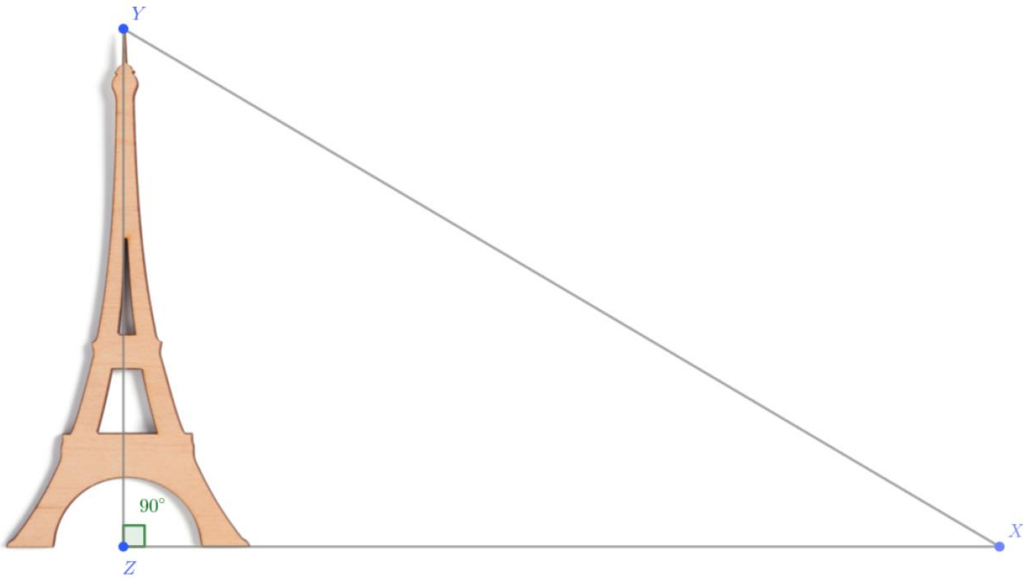


Modules C, D, E

The Eiffel Tower is 324 metres tall (the image is not to scale and for illustrative purposes only).

A tourist is standing at X. They are 310 meters from Z (the center of the base of the tower). What is the angle of elevation from the tourist to the top of the tower? Ignore the height of the tourist.

Give your answer in degrees. Make sure your calculator is set to degrees.
Round your answer to the nearest degree.



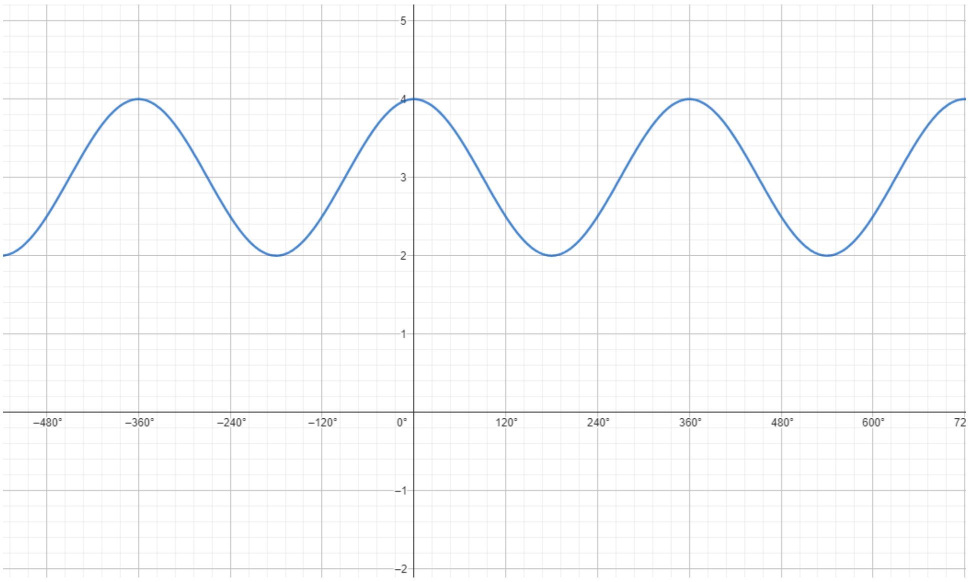
Modules D, E

Simplify the expression $-6\sqrt{a} - 2\sqrt{25a} + 5\sqrt{4a}$.

... $\square\sqrt{a}$ ...

Modules C, D, E

Which of the following functions matches the graph below? Note θ is measured in degrees.



a. $f(\theta) = 3\cos(\theta) + 1$

b. $f(\theta) = -\sin(\theta) + 4$

c. $f(\theta) = \cos(\theta) + 3$

d. $f(\theta) = 4\cos(\theta) + 4$

Modules D, E

Find a fraction or integer c such that $\log_7(6) + \log_7(11) - \log_7(12) = \log_7(c)$.

$c =$ ....

Modules D, E

The sine rule is $\frac{a}{\sin(A)} = \frac{b}{\sin(B)} = \frac{c}{\sin(C)}$ where a, b, and c are the lengths of a triangle and A, B, and C are the angles of the triangle opposite those sides respectively.

Consider the following triangle.

GeoGebra

Determine x, rounded to two decimal places. Make sure your calculator is set to degrees.

$x \approx$ ....

Modules D, E

Aoibhe hired a bike during their holiday. The insurance was €22 regardless of the number of hire days and the hire fee was an additional €33 per day.

If the total cost of the bike was €187, how many days did Aoibhe hire the bike for.

.... days

Module B

The Irish government wants to estimate the costs and the profit that would be created by constructing a wind power station. The following formula is proposed for estimating the financial gain, F euros, over a number of years y, if they build the E-63 model.

$$F = 1090000\,y - 8720000,$$

where the profit from the yearly production of electricity is €1090000 and the cost of building the wind power station is €8720000.

Based on this formula, what is the minimum number of years of operation required to cover the cost of construction of the wind power station?

.... years

Module B

Algebra

Solve the following system of equations.

$$\begin{cases} y - x &= -1 \\ x - 2\,y &= -1 \end{cases}$$

Give your answer in the form $\begin{cases} x &= a \\ y &= b \end{cases}$ with the correct values for a and b.

Modules A, B, C, D, E

Write $\frac{7}{6\,x} + \frac{2}{11\,x+12}$ as a single, simplified, fraction.

$\frac{7}{6\,x} + \frac{2}{11\,x+12} = \ldots \frac{\square}{\square} \ldots$

Modules A, B, C, D, E

Complete the polynomial expression below, whose roots are $x = -3$ and $x = 2$.

You may enter negative numbers by using the "$-$" key.

$y = \ldots\ x^2 + \square x + \square \ldots$

Modules A, B, C, D, E

Given the equation $g^3 = 5\,h\,f + k^5$. Rearrange the equation in terms of f.

$\ldots\ f = \square \ldots$

Modules A, B, C, D, E

Express $(x^6 x^{-5} y^6 y^{-1})^{13}$ as $x^a y^b$ with appropriate values for a and b.

$\ldots\ x^{\square} y^{\square}\ \ldots$

Modules A, B, C, D, E

Which of the following options equals $\left(-7\,x^2 + 8\,x + 8\right)\left(-x^2 + 9\,x + 9\right)$.

a. $7\,x^4 + 72\,x^2 + 72$
b. $7\,x^4 - 71\,x^3 + x^2 + 144\,x + 72$
c. $7\,x^4 - 71\,x^3 + x^2 + 72\,x + 72$
d. $7\,x^4 - 71\,x^3 + 9\,x^2 + 144\,x + 72$

Modules A, B

Solve $-4 \leq 3\,x + 3 < 3$.

Please give your answer as a fraction or correct to 2 decimal places.

.... $\leq x <$ ....

Modules A, B, C, D, E

When solving the equation $x^3 - 2x^2 + x = 0$, which of the following options describe the roots of the equation?

a. The solutions of the equation are $x = 0$ and $x = 1$ and 1 is a repeated root.

b. The solutions of the equation are $x = 0$ and $x = 1$ and 0 is a repeated root.

c. The solutions of the equation are $x = -1$ and $x = 1$.

d. The solutions of the equation are $x = 0$, $x = -1$, and $x = 1$.

Modules A, B, C, D, E

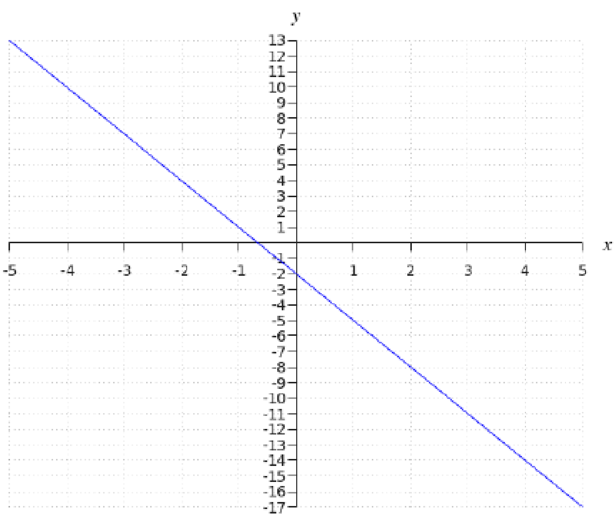
Expand the expression $(x+2)^4$.

Note the binomial theorem $(x+y)^n = \sum_{k=0}^{n} \binom{n}{k} x^{n-k} y^k$ may be helpful here.

Modules D, E

Functions and Calculus

The following diagram shows the graph of the function $y = m\,x + c$. What are the values of m and c?
Note that both m and c only take whole number values.



Modules A, B, C

Consider the function,

$$f(x) = 8\,x^3 + 6\,x^2 - 9\,x + 8$$

Calculate $f(-2)$, the function value when $x = -2$.

$f(-2) =$ ....

Modules A, B, C

If $g(x) = x^2 + x + 4$. For which real values is $g(x) = 10$.

The formula $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ may help.

Give your answer as:

- *none* if there is no real solution,
- $x = x_1$ if there is one real solution,
- $x = x_1 \vee x = x_2$ if there are two real solutions.
  You can find the $\vee$ symbol on the virtual keyboard on tab "Standard",

Use the correct values of x_1 and x_2.

Modules A, B, C (in Algebra), D, E

Is $y^4 = -4 - 5\,x$ a function?

a. Yes, always.

b. No, never.

c. It depends.

Modules A, B, C, D, E

What is the range (or image) of the function $h(x) = 9 - 4\,x$ when $-7 \leq x \leq 5$.

The range is: 37 ($<$ / $\leq$ / $>$ / $\geq$) $h(x)$ ($<$ / $\leq$ / $>$ / $\geq$) -11.

Modules A, B, C, D, E

What is the derivative of the polynomial function $f(x) = 6\,x^6 - 7$? Simplify your answer as much as possible.

$f'(x) =$ ....

Modules A, B, C

The derivative of a function is positive everywhere on the interval $[5, 10]$.
Where on the interval does the function have its minimum value (or lowest point)?

a. 5

b. 6

c. 10

d. There is no minimum.

Modules A, B, C, D, E

A sofa factory produces n sofas per hour.
The costs of running the factory is given by $C(n) = n^2 - 52\,n + 705$ for $n \geq 1$.

How many sofas should the factory produce per hour to keep the costs to a minimum?

.... sofas per hour.

Modules A, B, C, D, E

Indicate which of the following functions are antiderivatives of the function

$$f(x) = -3\,x^{-4} + 6$$

Recall that all functions $F(x)$ for which $F'(x) = f(x)$ are antiderivatives of $f(x)$.

a. $F(x) = x^{-3} + 6\,x + 5$

b. $F(x) = x^{-3}$

c. $F(x) = x^{-3} + 6$

d. $F(x) = 12\,x^{-5} + 6\,x^2$

e. $F(x) = 12\,x^{-5} + 6\,x + 5$

f. $F(x) = 12\,x^{-5}$

g. $F(x) = x^{-3} + 6\,x^2 + 5$

h. $F(x) = x^{-3} + 6\,x$

Modules D, E

What is the first derivative with respect to x of $f(x) = \cos(x + 7) - 4\,x^2 - 9$?

$f'(x) =$ ....

Modules D, E

A phone company has three different rates for calls given by the following function:

$$C(m) = \begin{cases} 7m + 7, & \text{between } 7:00 \text{ and } 17:00 \\ 6m + 3, & \text{between } 17:00 \text{ and } 22:00 \\ 3m + 2, & \text{between } 22:00 \text{ and } 7:00 \end{cases}$$

where m is the length of the call in minutes and $C(m)$ is the cost of the call in cents.

What is the cost of a 7 minute call that starts at 23 : 00?

Note, 24 hour clock notation is being used here.

.... cents

Modules C, D, E

Appendix K: MathsFit feedback emails

Students' feedback emails depended on the medal they achieved in each of the three sections of the MathsFit quiz (the medal terminology was used from 2021 onwards). With three medals (Gold, Silver and Bronze in 2021 and 2022 or High, Medium and Low in 2020) there were 27 possible feedback emails for students' first attempt and another 27 for their second attempt. These were organised into four classifications of support measures suggested in the first set of feedback emails and corresponded to different percentage amounts of module continuous assessment (if available for participating in MathsFit):

1. Achieved all Golds or Highs. No support suggested and invited to help lead a study group.
2. Achieved all Silvers or a mix of Golds and Silvers (Highs and Mediums). Engagement with the Refresher Course suggested for the sections Silver (Medium) was achieved in.
3. Achieved one Bronze (Low) and a mix of Golds and/or Silvers (Highs and Mediums). A visit to the Maths Support Centre about the section Bronze was achieved in suggested alongside engagement with the Refresher Course the sections Silver (Medium) or Bronze was achieved in.
4. Achieved two or three Bronzes. A visit to the Maths Support Centre about the sections Bronze was achieved in suggested alongside engagement with the Refresher Course the sections Silver (Medium) or Bronze was achieved in. Invitation to a study group issued.

An example of an email from each category for both the first and second attempts for each year is now provided. Examples from all modules involved were included so the varying language used for Module A who did not receive any continuous assessment for participating and the other modules who did is shown. Bold writing with in a feedback email indicates that the word was hyperlinked.

2020 version

Classification 1:

Attempt 1

Dear *Student's First Name*,

Well done for completing MathsFit and thank you for completing the survey too.

In the Arithmetic and Trigonometry section you gained greater than or equal to 18 marks (out of 20).
In the Algebra section you gained greater than or equal to 18 marks (out of 20).
In the Functions and Calculus section you gained greater than or equal to 18 marks (out of 20).

Congratulations, you have shown a High proficiency level in MathsFit and you have gained 3% of your MATH10030 assessment marks.

You are currently well prepared to continue to learn mathematics at third level.

We would like to invite you to help lead a group of your peers in your degree in a maths study group. You and 3-4 other students, who we recommended revise the topics from MathsFit, would meet virtually under the supervision of a Maths Support Centre Tutor for the first couple of weeks of Trimester 1. This would aid the other students in improving their maths proficiency, you in your confidence as a leader of your peers and your ability to tutor, and hopefully all of the group members in making friends in the early stages of university.

Research shows that acting as a peer leader, as you would be doing, does improve both your mathematics knowledge and your communication skills and so we would encourage you to participate. However, this is not mandatory. If you would like to participate please email claire.mullen@ucdconnect.ie.

If you encounter further questions or problems during your revision or your future maths learning at UCD you are always welcome to avail of the MSC. The MSC also offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. For more information see the MSC website.

Well done again on your MathsFit result and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Attempt 2
Dear *Student's First Name,*

Well done for resitting MathsFit. The following are the best results out of your two MathsFit attempts.

In the Arithmetic and Trigonometry section you gained greater than or equal to 18 marks (out of 20).
In the Algebra section you gained greater than or equal to 18 marks (out of 20).
In the Functions and Calculus section you gained greater than or equal to 18 marks (out of 20).

Congratulations, you have shown a High proficiency level in MathsFit and you have gained 3.3% of your MATH10030 assessment marks.

By engaging in revision you will have improved your maths proficiency even if your overall category grouping has not changed. Studies show that engaging in maths support does positively benefit students' overall grades.

Your maths proficiency will continue to improve as you engage with the MATH10030 material as the trimester continues.

We hope by engaging in MathsFit you have found any gaps in your knowledge and feel better prepared for university maths.

If you encounter any maths questions or problems during your maths learning here at UCD, you are always welcome to avail of the Maths Support Centre (MSC). The MSC offers one-to-one or small group support sessions with experienced maths tutors, both virtually and on campus, for first and second year maths and statistics modules. For more information, see the MSC Website.

Well done again on completing MathsFit twice and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Classification 2:

Attempt 1:
Dear *Student's First Name*,

Well done for completing MathsFit and thank you for completing the survey too.

In the Arithmetic and Trigonometry section you gained greater than or equal to 18 marks (out of 20).
In the Algebra section you gained greater than or equal to 14 marks and less than 18 marks (out of 20).
In the Functions and Calculus section you gained greater than or equal to 18 marks (out of 20).

Congratulations, you have shown a Medium-High proficiency level in MathsFit. You have gained 2% out of the 3% of your MATH10030 assessment marks for now.

You are currently well prepared to continue to learn mathematics at third level in most areas.

We would recommend you engage in a brief revision of Algebra. There are a selection of videos about these topics available **here** (the key for the course is MathsFit10030).

Once you engage in this revision, you can retake MathsFit to gain the extra 1%. To do this return to the same Brightspace page after 9 a.m. on Sunday 4th October and complete MathsFit by 5 p.m. on Friday 9th October.

If you encounter further questions or problems during your revision or your future maths learning at UCD you are always welcome to avail of the MSC. The MSC also offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. For more information see the **MSC website**.

Well done again on completing MathsFit and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Attempt 2:
Dear *Student's First Name*,

Well done for resitting MathsFit. The following are the best results out of your two MathsFit attempts.

In the Arithmetic and Trigonometry section you gained greater than or equal to 18 marks (out of 20).
In the Algebra section you gained greater than or equal to 14 marks and less than 18 marks (out of 20).
In the Functions and Calculus section you gained greater than or equal to 14 marks and less than 18 marks (out of 20).

You have shown a Medium proficiency level in MathsFit. You have gained 3.3% out of the 3.3% of your MATH10030 assessment marks.

By engaging in revision you will have improved your maths proficiency even if your overall category grouping has not changed. Studies show that engaging in maths support does positively benefit students' overall grades.

Your maths proficiency will continue to improve as you engage with the MATH10030 material as the trimester continues.

We hope by engaging in MathsFit you have found any gaps in your knowledge and feel better prepared for university maths.

If you encounter any maths questions or problems during your maths learning here at UCD, you are always welcome to avail of the Maths Support Centre (MSC). The MSC offers one-to-one or small group support sessions with experienced maths tutors, both virtually and on campus, for first and second year maths and statistics modules. For more information, see the **MSC Website**.

Well done again on completing MathsFit twice and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Classification 3:

Attempt 1:
Dear *Student's First Name*,

Well done for completing MathsFit and thank you for completing the survey too.

In the Arithmetic and Trigonometry section you gained greater than or equal to 18 marks (out of 20).
In the Algebra section you gained greater than or equal to 14 marks and less than 18 marks (out of 20).
In the Functions and Calculus section you gained less than 14 marks (out of 20).

You have shown a Low-Medium proficiency level in MathsFit.

We are concerned about your proficiency level in Functions and Calculus and recommend you take action to revise/learn this material in the early weeks of university so you are not hindered in your learning of university mathematics. Your proficiency level is changeable and we are here to support you in improving it.

We recommend engaging with the resources available **here** (the key for the course is MathsFit10230) and attending the Maths Support Centre (MSC) 'Hot Topics'. A 'Hot Topic' is an individual learning session run by an experienced maths tutor virtually through the MSC. You and the tutor can concentrate on solving the specific problems you have with a mathematical topic. Please book yourself in for a Hot Topic **here**. Choose a day and time that suits you and you will receive the support you need.

We also would recommend you engage in a brief revision of Algebra. There are a selection of videos about these topics available **here**.

After engaging in this revision we believe you will be well prepared for university mathematics. Some work now will improve your success in the future.

You can also retake MathsFit if you like, preferably after engaging with some maths support. To do this return to the same Brightspace page after 9 a.m. on Wednesday 7th October and complete MathsFit by 5 p.m. on Monday 12th October.

If you encounter further questions or problems during your revision or your future maths learning at UCD you are always welcome to avail of the MSC. The MSC also offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. For more information see the **MSC website**.

Well done again on completing MathsFit and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Attempt 2:
Dear *Student's First Name*,

Well done for resitting MathsFit. The following are the best results out of your two MathsFit attempts.

In the Arithmetic and Trigonometry section you gained less than 14 marks (out of 20).
In the Algebra section you gained greater than or equal to 18 marks (put of 20).
In the Functions and Calculus section you gained greater than or equal to 14 marks and less than 18 marks (out of 20).

You have shown a Low-Medium proficiency level in MathsFit.

By engaging in revision you will have improved your maths proficiency even if your overall category grouping has not changed. Studies show that engaging in maths support does positively benefit students' overall grades.

Your maths proficiency will continue to improve as you engage with the MATH10230 material as the trimester continues.

We hope by engaging in MathsFit you have found any gaps in your knowledge and feel better prepared for university maths.

If you encounter any maths questions or problems during your maths learning here at UCD, you are always welcome to avail of the Maths Support Centre (MSC). The MSC offers one-to-one or small group support sessions with experienced maths tutors, both virtually and on campus, for first and second year maths and statistics modules. For more information, see the MSC Website.

Well done again on completing MathsFit twice and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Classification 4:

Attempt 1:
Dear *Student's First Name*,

Well done for completing MathsFit and thank you for completing the survey too.

In the Arithmetic and Trigonometry section you gained less than 14 marks (out of 20).
In the Algebra section you gained less than 14 marks (out of 20).
In the Functions and Calculus section you gained less than 14 marks (out of 20).

You have shown a Low proficiency level in MathsFit.

We are concerned about your proficiency level in all three topics and recommend you take action to revise/learn this material in the early weeks of university so you are not hindered in your learning of university mathematics. Your proficiency level is changeable and we are here to support you.

We recommend engaging with the resources available **here** (the key for the course is MathsFit10230) and attending the Maths Support Centre (MSC) 'Hot Topics'. A 'Hot Topic' is an individual learning session run by an experienced maths tutor virtually through the MSC. You and the tutor can concentrate on solving the specific problems you have with a mathematical topic. Please book yourself in for a Hot Topic **here**. Choose a day and time that suits you and you will receive the support you need.

We also recommend that you join the study group scheme we are running. A small group of your peers will meet for the first 2-3 weeks of university (or longer if the group decides to continue) to revise mathematics together. Some of the students will also have shown a low proficiency level in MathsFit and some will have a high proficiency level. The initial sessions will be facilitated by a MSC tutor. We hope this will be an opportunity to work together with your peers to improve your proficiency level and also to make friends in the early stages of university. This is recommended but optional, so if you would like to join a study group please write ‘I would like to join a study group’ in the Additional Comments section of the Hot Topics Registration form linked above.

After engaging in this revision we believe you will be well prepared for university mathematics. Some work now will improve your success in the future.

You can also retake MathsFit if you like, preferably after engaging with some maths support. To do this return to the same Brightspace page after 9 a.m. on Wednesday 7th October and complete MathsFit by 5 p.m. on Monday 12th October.

If you encounter further questions or problems during your revision or your future maths learning at UCD you are always welcome to avail of the MSC. The MSC also offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. For more information see the **MSC website**.

Well done again on completing MathsFit and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Attempt 2:
Dear *Student's First Name*,

Well done for resitting MathsFit. The following are the best results out of your two MathsFit attempts.

In the Arithmetic and Trigonometry section you gained less than 14 marks (out of 20).
In the Algebra section you gained greater than or equal to 14 marks and less than 18 marks (out of 20).

In the Functions and Calculus section you gained less than 14 marks (out of 20).

You have shown a Low proficiency level in MathsFit.

By engaging in revision you will have improved your maths proficiency even if your overall category grouping has not changed. Studies show that engaging in maths support does positively benefit students' overall grades.

Your maths proficiency will continue to improve as you engage with the MATH10230 material as the trimester continues.

We hope by engaging in MathsFit you have found any gaps in your knowledge and feel better prepared for university maths.

If you encounter any maths questions or problems during your maths learning here at UCD, you are always welcome to avail of the Maths Support Centre (MSC). The MSC offers one-to-one or small group support sessions with experienced maths tutors, both virtually and on campus, for first and second year maths and statistics modules. For more information, see the **MSC Website**.

Well done again on completing MathsFit twice and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

2021 version

Classification 1:

Attempt 1:
Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Gold in the Arithmetic and Trigonometry Section.
You achieved Gold in the Algebra section.

You achieved Gold in the Functions and Calculus section.

You have earnt 3% of your MATH10420 assessment marks.

You are MathsFit!

If you would like to help your peers get more MathsFit, please email claire.mullen@ucdconnect.ie about helping lead a study group with tutors in the Maths Support Centre during the first few weeks of Trimester 1. Research suggests that acting as a peer leader improves both your mathematics knowledge and your communication skills.

You are always welcome at the **Maths Support Centre** (MSC) if you need any maths or statistics help. The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. We're here to keep you MathsFit!

Well done again and remember you can only get more MathsFit.

Kind regards,
Claire and Anthony

Attempt 2:
Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Gold in the Arithmetic and Trigonometry Section.
You achieved Gold in the Algebra section.
You achieved Gold in the Functions and Calculus section.

You have earnt 3% of your MATH10420 assessment marks.

You are MathsFit!

We hope by engaging in MathsFit you have found any gaps in your knowledge and feel better prepared for university maths.

Remember you are always welcome at the **Maths Support Centre** (MSC) if you need any maths or statistics help. The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. We're here to keep you MathsFit!

Well done again and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Classification 2:

Attempt 1:
Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Gold in the Arithmetic and Trigonometry Section.
You achieved Silver in the Algebra section.
You achieved Silver in the Functions and Calculus section.

You have earnt 2% of your MATH10310 assessment marks.

To earn the full 3% available, go for gold in Algebra and Functions and Calculus by engaging with our Refresher course available in your MATH10310 Brightspace page and completing the quiz again. The quiz will be available between 8am and 8pm daily until Friday 8th October.

You are always welcome at the **Maths Support Centre** (MSC) if you need any maths or statistics help. The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. We're here to keep you MathsFit!

Well done again and remember you can only get more MathsFit.

Kind regards,
Claire and Anthony

Attempt 2:
Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Silver in the Arithmetic and Trigonometry Section.
You achieved Silver in the Algebra section.
You achieved Gold in the Functions and Calculus section.

You have earnt 3% of your MATH10310 assessment marks.

You are more MathsFit!

We hope by engaging in MathsFit you have found any gaps in your knowledge and feel better prepared for university maths.

Remember you are always welcome at the **Maths Support Centre** (MSC) if you need any maths or statistics help. The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. We're here to keep you MathsFit!

Well done again and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Classification 3:

Attempt 1:

Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Bronze in the Arithmetic and Trigonometry Section.

You achieved Gold in the Algebra section.

You achieved Gold in the Functions and Calculus section.

You have earnt 1% of your MATH10030 assessment marks.

To earn the full 3% available, go for gold in Arithmetic by engaging with our Refresher course, available in your MATH10030 Brightspace page, and completing the quiz again. The quiz will be available between 8am and 8pm daily until Friday 8th October.

We also recommend a visit with a Maths Support tutor at the **Maths Support Centre** (MSC) to look at any specific parts of Arithmetic you need help with. Individual and group sessions are available, see the MSC website for times.

The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. We're here to keep you MathsFit!

Well done again and remember you can only get more MathsFit.

Kind regards,

Claire and Anthony

Attempt 2:

Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Gold in the Arithmetic and Trigonometry Section.
You achieved Silver in the Algebra section.
You achieved Bronze in the Functions and Calculus section.

You have earnt 2.2% of your MATH10030 assessment marks.

You are more MathsFit!

We hope by engaging in MathsFit you have found any gaps in your knowledge and feel better prepared for university maths.

Remember you are always welcome at the **Maths Support Centre** (MSC) if you need any maths or statistics help. The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. We're here to keep you MathsFit!

Well done again and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Classification 4:

Attempt 1:
Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Bronze in the Arithmetic and Trigonometry Section.
You achieved Bronze in the Algebra section.
You achieved Gold in the Functions and Calculus section.

We recommend you go for gold in Arithmetic and Trigonometry and Algebra by engaging with our Refresher course, available in your MATH10230 Brightspace page, and completing the quiz again. The quiz will be available between 8am and 8pm daily until Friday 8th October.

We also recommend a visit with a Maths Support tutor at the Maths Support Centre (MSC) to look at any specific parts of Arithmetic and Trigonometry and Algebra you need help with. Individual and group sessions are available, see the **MSC website** for times.

The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. We're here to keep you MathsFit!

Joining a study group with your peers for the first few weeks of the trimester, facilitated by the MSC, may also help you become more MathsFit. Please email claire.mullen@ucdconnect.ie if you are interested.

Well done again and remember you can only get more MathsFit.

Kind regards,
Claire and Anthony

Attempt 2:
Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Bronze in the Arithmetic and Trigonometry Section.
You achieved Bronze in the Algebra section.
You achieved Silver in the Functions and Calculus section.

You are more MathsFit!

We hope by engaging in MathsFit you have found any gaps in your knowledge and feel better prepared for university maths.

Remember you are always welcome at the **Maths Support Centre** (MSC) if you need any maths or statistics help. The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. We're here to keep you MathsFit!

Well done again and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

2022 version

Classification 1:

Attempt 1:
Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Gold in the Arithmetic and Trigonometry Section.
You achieved Gold in the Algebra section.
You achieved Gold in the Functions and Calculus section.

You are MathsFit!

If you wish to review your quiz answers and the solutions you can do so by going to the Bolster Academy home page (through the Refresher Course link in Brightspace), clicking Report in the top banner, then Tests then Review in the Score column.

If you would like to help your peers get more MathsFit, email claire.mullen@ucdconnect.ie about helping lead a study group with tutors in the UCD Maths Support Centre during the first few weeks of Trimester 1. Research shows that acting as a peer leader, as you would be doing, does improve both your mathematics knowledge and your communication skills.

You are always welcome at the UCD Maths Support Centre (MSC) if you need any maths or statistics help. The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. See **www.ucd.ie/msc** for further details. We're here to keep you MathsFit!

Well done again and remember you can only get more MathsFit.

Kind regards,
Claire and Anthony

Attempt 2:
Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Gold in the Arithmetic and Trigonometry Section.
You achieved Gold in the Algebra section.
You achieved Gold in the Functions and Calculus section.

You are MathsFit!

We hope by engaging in MathsFit you have found any gaps in your knowledge and feel better prepared for university maths.

If you wish to review your quiz answers and the solutions you can do so by going to the Bolster Academy home page (through the Refresher Course link in Brightspace), clicking Report in the top banner, then Tests then Review in the Score column.

Remember, you are always welcome at the Maths Support Centre (MSC) if you need any maths or statistics help. The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. See **www.ucd.ie/msc** for further details. We're here to keep you MathsFit!

Well done again and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Classification 2:

Attempt 1:
Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Gold in the Arithmetic and Trigonometry Section.
You achieved Silver in the Algebra section.
You achieved Gold in the Functions and Calculus section.

You have earnt 2.2% of your MATH10030 assessment marks.

To earn the full 3.3% available, go for gold in Algebra by engaging with our Refresher course, available in your MATH10030 Brightspace page, and completing the quiz again in the Attempt 2 section of Brightspace. The quiz will be available until Friday 7th October.

If you wish to review your quiz answers and the solutions you can do so by going to the Bolster Academy home page (through the Refresher Course link in Brightspace), clicking Report in the top banner, then Tests then Review in the Score column.

You are always welcome at the Maths Support Centre (MSC) if you need any maths or statistics help. The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. We're here to keep you MathsFit!

Well done again and remember you can only get more MathsFit.

Kind regards,

Claire and Anthony

Attempt 2:

Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Gold in the Arithmetic and Trigonometry Section.
You achieved Silver in the Algebra section.
You achieved Silver in the Functions and Calculus section.

You have earnt 2.7% of your MATH10030 assessment marks.

You are more MathsFit!

We hope by engaging in MathsFit you have found any gaps in your knowledge and feel better prepared for university maths.

If you wish to review your quiz answers and the solutions you can do so by going to the Bolster Academy home page (through the Refresher Course link in Brightspace), clicking Report in the top banner, then Tests then Review in the Score column.

Remember, you are always welcome at the Maths Support Centre (MSC) if you need any maths or statistics help. The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. See **www.ucd.ie/msc** for further details. We're here to keep you MathsFit!
Well done again and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Classification 3:

Attempt 1:

Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Bronze in the Arithmetic and Trigonometry Section.
You achieved Silver in the Algebra section.
You achieved Silver in the Functions and Calculus section.

You have earnt 1.5% of your MATH10250 assessment marks.

To earn the full 3% available, go for gold in Arithmetic and Trigonometry, Algebra and Functions and Calculus by engaging with our Refresher course, available in your MATH10250 Brightspace page, and completing the quiz again in the Attempt 2 section of Brightspace. The quiz will be available until Friday 7th October. You can do it!

If you wish to review your quiz answers and the solutions you can do so by going to the Bolster Academy home page (through the Refresher Course link in Brightspace), clicking Report in the top banner, then Tests then Review in the Score column.

We also recommend a visit with a Maths Support tutor at the UCD Maths Support Centre (MSC) to look at any specific parts of Arithmetic and Trigonometry you need help with. Individual and group sessions are available, see **www.ucd.ie/msc** for times.

The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. See www.ucd.ie/msc for further details. We're here to keep you MathsFit!

Well done again and remember you can only get more MathsFit.

Kind regards,
Claire and Anthony

Attempt 2:
Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Bronze in the Arithmetic and Trigonometry Section.
You achieved Gold in the Algebra section.
You achieved Silver in the Functions and Calculus section.

You have earnt 2% of your MATH10250 assessment marks.

You are more MathsFit!

We hope by engaging in MathsFit you have found any gaps in your knowledge and feel better prepared for university maths. We recommend you keep improving your MathsFitness by engaging with the MSC (**www.ucd.ie/msc**). Joining a study group with your peers for the first few weeks of the trimester, facilitated by the MSC, may also help you become more MathsFit. Please email claire.mullen@ucdconnect.ie if you are interested.

If you wish to review your quiz answers and the solutions you can do so by going to the Bolster Academy home page (through the Refresher Course link in Brightspace), clicking Report in the top banner, then Tests then Review in the Score column.

Remember, you are always welcome at the Maths Support Centre (MSC) if you need any maths or statistics help. The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. See **www.ucd.ie/msc** for further details. We're here to keep you MathsFit!

Well done again and we wish you all the best with your UCD experience, especially your maths learning.

Kind regards,
Claire and Anthony

Classification 4:

Attempt 1:

Dear *Student's First Name*,

Congratulations on completing the MathsFit quiz!

You achieved Bronze in the Arithmetic and Trigonometry Section.
You achieved Silver in the Algebra section.
You achieved Bronze in the Functions and Calculus section.

You have earnt 1% of your MATH10310 assessment marks.

To earn the full 3% available, go for gold in Arithmetic and Trigonometry, Algebra, and Functions and Calculus.

by engaging with our Refresher course, available in your MATH10310 Brightspace page, and completing the quiz again in the Attempt 2 section of Brightspace. The quiz will be available until Friday 7th October. You can do it!

If you wish to review your quiz answers and the solutions you can do so by going to the Bolster Academy home page (through the Refresher Course link in Brightspace), clicking Report in the top banner, then Tests then Review in the Score column.

We also recommend a visit with a Maths Support tutor at the Maths Support Centre (MSC) to look at any specific parts of Arithmetic and Trigonometry and Functions and Calculus you need help with. Individual and group sessions are available, see www.ucd.ie/msc for times.

The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. See **www.ucd.ie/msc** for further details. We're here to keep you MathsFit!

Joining a study group with your peers for the first few weeks of the trimester, facilitated by the MSC, may also help you become more MathsFit. Email claire.mullen@ucdconnect.ie if you are interested.

Well done again and remember you can only get more MathsFit.

Kind regards,
Claire and Anthony

Attempt 2:
Dear *Student's First Name*,
Congratulations on completing the MathsFit quiz!

You achieved Silver in the Arithmetic and Trigonometry Section.
You achieved Bronze in the Algebra section.
You achieved Bronze in the Functions and Calculus section.

You have earnt 1.5% of your MATH10310 assessment marks.

You are more MathsFit!

We hope by engaging in MathsFit you have found any gaps in your knowledge and feel better prepared for university maths. We recommend you keep improving your MathsFitness by engaging with the MSC (www.ucd.ie/msc). Joining a study group with your peers for the first few weeks of the trimester, facilitated by the MSC, may also help you become more MathsFit. Please email claire.mullen@ucdconnect.ie if you are interested.

If you wish to review your quiz answers and the solutions you can do so by going to the Bolster Academy home page (through the Refresher Course link in Brightspace), clicking Report in the top banner, then Tests then Review in the Score column.

Remember, you are always welcome at the Maths Support Centre (MSC) if you need any maths or statistics help. The MSC offers one-to-one or small group support sessions with experienced maths tutors both virtually and on campus for first and second year maths and statistics modules. See **www.ucd.ie/msc** for further details. We're here to keep you MathsFit!

Well done again and we wish you all the best with your UCD experience, especially your maths learning.
Kind regards,
Claire and Anthony

Appendix L: MathsFit information letter

September 2022

Introductory statement
You are being invited to take part in the research project titled "**Using Learning Analytics to Aid Student Success**". This research is being conducted by Claire Mullen, PhD student in the UCD School of Mathematics and Statistics, and Dr Anthony Cronin**,** Assistant Professor at the UCD School of Mathematics and Statistics. Before you decide to take part it is important you understand why the research is being conducted and what it will involve. Please take the time to read the following information carefully.

What is this research about?
Since March 2020 secondary schools and other places of education have experienced repeated closures and disruption due to the COVID-19 pandemic. This study is focused on: early identification of students who may be at-risk of under-performing in their mathematics modules due to the disruption of their previous education; and on implementing targeted interventions to support such students. The study will involve a survey about your previous experience of the mathematics subject as well as a mathematics proficiency quiz to gauge where you are mathematically as you start your university mathematics learning.

Our research questions are:

1. What areas of improvement, if any, can be identified in incoming students' mathematics proficiency based on the results of their proficiency quiz?
2. For those identified for follow up interventions, what worked best in terms of engaging students with mastery learning?
3. In what ways do students choose to interact with various maths support measures when participating in a first-year mathematics course?
4. What learnings around promoting independent study practice e.g. resilience, can be gained as a result of this study.

We are interested to see how differences in students' approaches to learning, and/or prior mathematical achievement affects their engagement with online mathematics support resources. Students' views on the differences between online learning versus traditional face-to-face support are also of interest.

How will my data be used?
The de-identified results from your proficiency quiz will be used to identify students potentially at risk of underperforming in their mathematics module and to advise on follow on supports. Further insights from examining Brightspace and Bolster Academy engagement metrics (e.g. downloads, clicks, videos watched) and results from early continuous assessment components may also be used to contact you if you are deemed at risk of falling behind in the module.

Why have you been invited to take part?
You are invited to participate in this study because you are enrolled in a Stage 1 mathematics module at UCD in the 2022/2023 academic year.

What are the benefits of taking part?
As part of this research you may be contacted with advice on how you might improve your chances of success within this mathematics module e.g. visit the UCD maths support centre, take an online class, advice on which resources/videos to view etc.

Are there any risks associated with taking part?
There are no foreseeable risks associated with taking part in the study. Taking part in this study is voluntary and will not affect the grades you achieve. It will also have no impact on any of your other academic activities, and these data will not be shared with anyone else or used by the School or University for other purposes.

Do I have to take part?
No – participation is voluntary, it is entirely up to you. You can still receive the full percentage of continuous assessment available for participating in MathsFit without consenting for your data to be used in the research.

Can I change my mind at any stage and withdraw from the study?
Yes of course, if you do decide to take part, you can decide to withdraw at any time or refuse to answer any question without any consequences of any kind. You can withdraw permission to use data from your survey responses up to the end of the study, in which case your survey will be deleted. A decision to withdraw, or not to take part, will not affect you in any way.

What will happen if I decide to take part?
You will be asked to take an online proficiency mathematics quiz and answer a number of survey questions regarding your mathematical background.
The questionnaire will take place online. You should feel comfortable to respond to the questions honestly and you will not be identifiable from the data you provide. The questionnaire should take around 5 minutes to complete. While we do ask for you to provide your student number so that the results of the proficiency test may be attributed to you in case of follow up guidance or interventions, your responses to this survey will have no effect on your results for this module, nor will it affect your relationship with your tutors or lecturers. It will also have no impact on any of your other academic activities, and these data will not be shared with anyone else or used by the School or University for other purposes.

How will your privacy be protected?
Your data will be processed in accordance with the General Data Protection Regulation 2016 (GDPR) and the Data Protection Act 2018. All information collected about you will be kept strictly confidential and secure. Your data will only be viewed by the research team. All electronic data will be stored on a password-protected computer file. If your data is used for research purposes it will be anonymised. Following the completion of the study all data relating to your participation will be archived and/or destroyed. If you choose to withdraw from the study your data will be destroyed immediately.

What will happen with the results of this study?
You can contact one of the research team who will be able to speak to you about the results of the study. The results of this study may be summarised in published articles, theses reports and presentations. Quotes or key findings will always be made anonymous in any formal outputs.

Contact Details

This research project has been approved by the Human Research Ethics Committee (HREC) of University College Dublin. If you are unhappy with any aspect of this research or have any questions about your participation, please contact either Claire Mullen or Dr Anthony Cronin using the details below.

If you have any concerns or complaints about the conduct of this research project, which you do not wish to discuss with the research team, you should contact the HREC team at hrec@ucd.ie

Claire Mullen:
Email: claire.mullen@ucdconnect.ie

Dr Anthony Cronin
Email: anthony.cronin@ucd.ie
Phone: 01 716 7536 or 087 768 7316

Informed Consent

By participating in this study you consent to: (1) your proficiency quiz score being used to identify any areas of improvement so that appropriate follow up maths support interventions or recommendations may be made; (2) your anonymous survey information to be used for research purposes so that insights on how to better support at-risk students may be found; and (3) your anonymous Brightspace and Bolster Academy engagement metrics (no. of downloads, views etc), including continuous and final module grades be used for research towards enabling student success.

Yes, I am happy to participate.
No, I would prefer not to participate.

Now you have read this information letter you can consent (or not consent) to participate in this study when you take the MathsFit pre-quiz survey.

Appendix M: MathsFit pre-survey

1. Having read the information letter, by participating in this study you consent to
    a. your proficiency quiz score being used to identify any areas of improvement so that appropriate follow up maths support interventions or recommendations may be made;
    b. your anonymous survey information to be used for research purposes so that insights on how to better support students may be found; and
    c. your anonymous Brightspace and Bolster Academy engagement metrics (no. of downloads, views etc.), including continuous and final module grades be used for research towards enabling student success.

    If you are not happy to participate, then please click no below and then click submit survey. Brightspace will warn you about unanswered questions but submit survey again, and confirm you want to submit without answering.
    Yes, I am happy to participate.
    No, I would prefer not to participate.

2. Are you aged 18 years or above? If you are not aged 18 years or above, we may not collect personal data from you, but you are welcome to take the quiz. In this case once you have clicked no below, click submit survey. Brightspace will warn you about unanswered questions but submit survey again, and confirm you want to submit without answering.
    Yes
    No

3. What is your gender?
    Male
    Female
    Non-binary
    Prefer not to say

4. Are you an international or domestic student?
    International
    Domestic

5. What degree are you currently studying for?
    Commerce
    Commerce International
    Business and Law
    Agricultural Science
    Agricultural Systems Technology
    Animal Science
    Animal and Crop Production
    Animal Science – Equine
    Food and Agribusiness Management
    Food Business with Chinese Studies
    Forestry
    Dairy Business
    Horticulture, Landscape and Sportsturf Management
    Agri-Environmental Sciences
    Food Science

Human Nutrition
Engineering
Biological, Biomedical & Biomolecular Sciences (BBB)
Chemistry & Chemical Sciences (CCS)
Mathematical, Physical & Geological Sciences (MPG)
No Preference Science
Other

6. Which final mathematics examination did you take most recently?
   Leaving Certificate
   QQI-FETAC
   UCD Access
   MSAP
   A-levels
   GCSEs
   International Baccalaureate
   SATs
   Other (please state which one in the next question)

7. What grade or mark did you obtain in the exam given in answer to the previous question?
   ____

8. How satisfied were you with your final exam mathematics results?
   Very Dissatisfied
   Dissatisfied
   Neutral
   Satisfied
   Very Satisfied

9. How satisfied were you with your secondary school/previous learning results overall?
   Very Dissatisfied
   Dissatisfied
   Neutral
   Satisfied
   Very Satisfied

10. What grade were you expecting to receive in mathematics?
    ____

11. Due to disruption caused by the pandemic, you may have been taught some mathematics topics in less detail or not at all. Are you aware of any topics you may not have studied? If yes please choose the appropriate topic(s) below that you believe were not covered (check all that apply).
    No, I think we covered the entire maths curriculum.
    I'm not sure.
    Yes, I think we missed a/some topic(s) in maths

    Constructions
    Coordinate Geometry
    Trigonometry
    Length, Area & Volume

Probability
Statistics
Financial Maths
Complex Numbers
Algebra
Differentiation
Integration (Higher Level only)
Sequences & Series
Functions

12. How much do you agree with the following statement?
    I feel anxious about taking the MathsFit quiz.
    Strongly disagree
    Disagree
    Neutral
    Agree
    Strongly agree

In 2020 the pre-survey question 12 also contained the following statements that students indicated their agreement with (using one of the five agreement levels above).
It wouldn't bother me at all to take more maths classes.
I have usually been at ease during maths tests.
I have usually been at ease in maths courses.
I usually don't worry about my ability to solve maths problems.
I almost never get uptight while taking maths tests.
I get really uptight during maths tests
I get a sinking feeling when I think of trying hard maths problems.
My mind goes blank and I am unable to think clearly when working on mathematics.
Mathematics makes me feel uncomfortable and nervous.
Mathematics makes me feel uneasy and confused.
I feel anxious about mathematics modules at university.

Appendix N: MathsFit post-survey

2020 version:

1. I had enough time to complete the Arithmetic and Trigonometry section of the quiz.
   True
   False

2. I had enough time to complete the Algebra section of the quiz.
   True
   False

3. I had enough time to complete the Calculus and Functions section of the quiz.
   True
   False

4. How much do you agree with the following statement?
   I felt anxious while I was taking the MathsFit quiz.
   Strongly disagree
   Disagree
   Neutral
   Agree
   Strongly agree

5. Do you have any comments you would like to leave regarding the quizzes or surveys?
   ____

2021 version:

Note in the 2021 quiz each question was accompanied by a confidence question asking students if they

a) Felt confident about their answer
b) Felt unsure about their answer
c) Did not know the answer

The 2021 post-survey asked:

1. I had enough time to complete the Arithmetic and Trigonometry section of the quiz.
   True
   False

2. I had enough time to complete the Algebra section of the quiz.
   True
   False

3. I had enough time to complete the Calculus and Functions section of the quiz.
   True
   False

4. In the Arithmetic and Trigonometry section, I mostly selected the following option:
   I felt confident about my answer before I submitted it.
   I was unsure about my answer before I submitted it.
   I did not know the answer.

5. In the Algebra section, I mostly selected the following option:
   I felt confident about my answer before I submitted it.
   I was unsure about my answer before I submitted it.
   I did not know the answer.

6. In the Functions and Calculus section, I mostly selected the following option:
   I felt confident about my answer before I submitted it.
   I was unsure about my answer before I submitted it.
   I did not know the answer.

7. How much do you agree with the following statement?
   I felt anxious while I was taking the MathsFit quiz.
   Strongly disagree
   Disagree
   Neutral
   Agree
   Strongly agree

8. Do you have any comments you would like to leave regarding the quizzes or surveys?
   ____

2022 version:

The 2022 quiz included the confidence questions that were in the 2021 post-survey and the quiz was not timed. The post-survey consisted of 2 questions:

1. How much do you agree with the following statement?
   I felt anxious while I was taking the MathsFit quiz.
   Strongly disagree
   Disagree
   Neutral
   Agree
   Strongly agree

2. Do you have any comments you would like to leave regarding the quizzes or surveys?
   ____

Attempt 2 post-survey

This survey was only taken by 2022 participants.

1. Please answer the following questions, paying attention to the different scale ratings.
   a) How difficult did you find the MathsFit quiz, 1 being very easy to 5 being very difficult?

      1

2

3

4

5

b) How did you feel about your results from your first attempt at the MathsFit quiz, 1 being very disappointed to 5 being very happy?

1

2

3

4

5

c) How clear was the communication about MathsFit, 1 being not at all clear to 5 being as clear as possible?

1

2

3

4

5

2. Have you engaged with the MathsFit Refresher Course in Brightspace/Bolster Academy?

Yes

No

3. If you have used the MathsFit Refresher Course, please rate its helpfulness. If you have not, please select N/A.

How helpful did you find the MathsFit Refresher Course, 1 being not at all helpful to 5 being extremely helpful.

1

2

3

4

5

N/A

4. Are you aware of the Maths Support Centre at UCD?

Yes
No

5. If you would like to explain the reasons for any of your answers or provide further feedback about MathsFit (including potential improvements) or maths support at UCD, please use this space. All feedback is welcome.

____

Appendix O: MathsFit follow-up survey

The follow up surveys were hosted in Google forms which meant the questions shown to students could be tailored to their previous answers. Therefore there are multiple versions of the quiz. These are divided into sections and when which section a student is shown depends on an answer the section that appears next will be indicated in *italics*. As the number of questions a student answered depended on their answers, no question numbers were used to avoid confusion.

2020 version

Last September/October in the first weeks of the Autumn Trimester you had the opportunity to participate in MathsFit, a proficiency quiz and survey hosted on your maths' module's Brightspace site. This very short survey asks questions about your experience of MathsFit and maths support in UCD.

Section 1

Which mathematics module did you take?

MATH10030 Maths for Business

MATH10230 Maths for Agriculture 1

How many times did you complete the MathsFit proficiency quiz?

0 times – didn't participate. *(Section 2)*

One – just the first attempt. *(Section 3)*

Twice – the first and second attempt. *(Section 4)*

Section 2: Those who selected "0 times – didn't participate" then answered:

What were the reasons, if any, you did not participate in MathsFit? Please select all that apply.

Late registration

Did not know about it

Did not want to participate

Lack of internet access

Lack of computer access

Could not find it in Brightspace

Taking a maths quiz in the first week of university made me feel anxious

Other ______

How clear was the communication (emails, the video) about MathsFit?

1 Not at all clear

2

3

4

5 As clear as possible

Are you aware of the Maths Support Centre in UCD? Have you used it before?

No I am not aware of the Maths Support Centre.

Yes I am aware if the Maths Support Centre and have not used it.

Yes I am aware if the Maths Support Centre and have used it.

Which of the following types of maths support, if any, did you use during the last academic year? Please select all that apply.

The UCD Maths Support Centre

MathsFit Moodle

Maths module tutors/lecturers

Peers in the same maths module

Family/friends not in the same maths module

Online resources – e.g. YouTube

Other ______

Can you suggest any ways to improve MathsFit? What would have encouraged you to participate, if anything?

____

If you would like to explain the reasons for any of your answers or provide any other feedback about MathsFit or maths support at UCD please use this space. All feedback is very welcome.

____

Would you be willing to volunteer for a brief Zoom interview with PhD student Claire Mullen to discuss your first year university mathematics experience in more depth?

Yes *(Final question)*

No *(End of survey)*

Section 3: Those who selected "One – just the first attempt" in Section 1 then answered:

How difficult did you find the MathsFit quiz?

1 Very easy

2

3

4

5 Very difficult

How did you feel about your MathsFit quiz result?

1 Very disappointed

2

3

4

5 Very happy

What were the reasons you attempted the MathsFit quiz once only? Please select all that apply.

The feedback email did not suggest a second attempt.

I did not want to complete a second attempt.

I did not have time to complete a second attempt.

I had trouble accessing the second attempt in Brightspace.

I did not know there was a second attempt.

Other ______

How clear was the communication (emails, the video, the Brightspace quiz) about MathsFit?

1 Not at all clear

2

3

4

5 As clear as possible

Did you use any of the support suggested in the feedback email you received after completing the MathsFit quiz? It may have suggested you watch some relevant videos on Moodle, book a session in the Maths Support Centre and/or join a study group.

No I did not use any of the support suggested. *(Section 5)*

No I did not receive a feedback email. *(Section 6)*

Yes, I watched videos on Moodle. *(Section 7)*

Yes, I watched videos on Moodle and visited the Maths Support Centre. *(Section 7)*

Yes, I watched videos on Moodle, visited the Maths Support Centre and joined a study group. *(Section 7)*

Yes, I visited the Maths Support Centre. *(Section 7)*

Yes, I visited the Maths Support Centre and joined a study group. *(Section 7)*

Yes, I joined a study group. *(Section 7)*

I cannot remember. *(Section 6)*

Other _______

Section 4: Those who selected "Twice – the first and second attempt" in Section 1 then answered:

How difficult did you find the MathsFit quiz?

1 Very easy

2

3

4

5 Very difficult

How did you feel about your MathsFit quiz result for your first attempt?

1 Very disappointed

2

3

4

5 Very happy

How did you feel about your MathsFit quiz result for your second attempt?

1 Very disappointed

2

3

4

5 Very happy

How clear was the communication (emails, the video, the Brightspace quiz) about MathsFit?

1 Not at all clear

2

3

4

5 As clear as possible

Between your first and second attempt of MathsFit there was a gap of at least 4 days (Attempt 1 was in Week 1 and Attempt 2 was in Week 2). In your opinion was this gap:

Too long.

Too short.

Just right?

Other ______

Please explain your answer to the previous question.

____

Did you use any of the support suggested in the feedback email you received after completing the MathsFit quiz for the first time? It may have suggested you watch some relevant videos on Moodle, book a session in the Maths Support Centre and/or join a study group.

No I did not use any of the support suggested. *(Section 5)*

No I did not receive a feedback email. *(Section 6)*

Yes, I watched videos on Moodle. *(Section 7)*

Yes, I watched videos on Moodle and visited the Maths Support Centre. *(Section 7)*

Yes, I watched videos on Moodle, visited the Maths Support Centre and joined a study group. *(Section 7)*

Yes, I visited the Maths Support Centre. *(Section 7)*

Yes, I visited the Maths Support Centre and joined a study group. *(Section 7)*

Yes, I joined a study group. *(Section 7)*

I cannot remember. *(Section 6)*

Other _______

Section 5 (those who did not use the suggested support):

For what reasons, if any, did you not use the suggested support?

____

Are you aware of the Maths Support Centre in UCD? Have you used it before?

No I am not aware of the Maths Support Centre.

Yes I am aware if the Maths Support Centre and have not used it.

Yes I am aware if the Maths Support Centre and have used it.

Which of the following types of maths support, if any, did you use during the last academic year? Please select all that apply.

The UCD Maths Support Centre

MathsFit Moodle

Maths module tutors/lecturers

Peers in the same maths module

Family/friends not in the same maths module

Online resources – e.g. YouTube

Other ______

Can you suggest any ways to improve MathsFit?

____

If you would like to explain the reasons for any of your answers or provide any other feedback about MathsFit or maths support at UCD please use this space. All feedback is very welcome.

____

Would you be willing to volunteer for a brief Zoom interview with PhD student Claire Mullen to discuss your first year university mathematics experience in more depth?

Yes *(Final question)*

No *(End of survey)*

Section 6 (those who did not receive a feedback email or could not remember)

Are you aware of the Maths Support Centre in UCD? Have you used it before?

No I am not aware of the Maths Support Centre.

Yes I am aware if the Maths Support Centre and have not used it.

Yes I am aware if the Maths Support Centre and have used it.

Which of the following types of maths support, if any, did you use during the last academic year? Please select all that apply.

The UCD Maths Support Centre

MathsFit Moodle

Maths module tutors/lecturers

Peers in the same maths module

Family/friends not in the same maths module

Online resources – e.g. YouTube

Other ______

Can you suggest any ways to improve MathsFit?

____

If you would like to explain the reasons for any of your answers or provide any other feedback about MathsFit or maths support at UCD please use this space. All feedback is very welcome.

____

Would you be willing to volunteer for a brief Zoom interview with PhD student Claire Mullen to discuss your first year university mathematics experience in more depth?

Yes *(Final question)*

No *(End of survey)*

Section 7 (those who did use the suggested support):

How helpful did you find the suggested support?

1 Not at all helpful

2

3

4

5 Very helpful

Please explain your answer to the previous question.

____

Which of the following types of maths support, if any, did you use during the last academic year? Please select all that apply.

The UCD Maths Support Centre

MathsFit Moodle

Maths module tutors/lecturers

Peers in the same maths module

Family/friends not in the same maths module

Online resources – e.g. YouTube

Other ______

Can you suggest any ways to improve MathsFit?

____

If you would like to explain the reasons for any of your answers or provide any other feedback about MathsFit or maths support at UCD please use this space. All feedback is very welcome.

____

Would you be willing to volunteer for a brief Zoom interview with PhD student Claire Mullen to discuss your first year university mathematics experience in more depth?

Yes *(Final question)*

No *(End of survey)*

Final question:

Thank you so much for volunteering to be interviewed. Please fill in your name and email address below and Claire, the researcher behind MathsFit, will be in contact soon to arrange a suitable time and date.

Please provide your name and ucdconnect email address (e.g. joe.bloggs@ucdconnect.ie)

____

2021 version

To prevent repetition, where a section of the 2021 survey is the same as the 2020 version, the phrase "See 2020 version" will be used instead of printing the full questions again. The 2021 follow-up survey began with:

At the start of this trimester you had the opportunity to participate in MathsFit, a proficiency quiz and refresher course hosted on your maths' module's Brightspace site. This very short survey asks questions about your experience of MathsFit and maths support in UCD.

Section 1

What is your student number?

____

If you took the Leaving Certificate in 2020 or 2021 did you sit the formal examination in mathematics or opt for only the "calculated grades" option?

I sat the Leaving Certificate Mathematics Exam.

I opted for only Calculated Grades.

I did not complete the Leaving Certificate in either 2020 or 2021.

Other ______

Which mathematics module are you currently completing?

MATH10030 Maths for Business

MATH10230 Maths for Agriculture 1

MATH10310 Calculus for Science

MATH10250 Intro Calculus for Engineers

MATH10420 Intro Calculus for Engineers (NUin)

How many times did you complete the MathsFit quiz?

0 times – didn't participate *(Section 2)*

Once – just the first attempt *(Section 3)*

Twice – the first and second attempt *(Section 4)*

More than twice *(Section 4)*

Section 2 (0 attempts):

See 2020 version.

Section 3 (1 attempt):

Did you experience technical difficulties while completing the MathsFit quiz? E.g. Numbas freezing, being unable to access all the questions.

Yes

No

How difficult did you find the MathsFit quiz?

1 Very easy

2

3

4

5 Very difficult

How did you feel about your MathsFit quiz result?

1 Very disappointed

2

3

4

5 Very happy

You were scheduled to complete the MathsFit quiz during your first tutorial. Would you have preferred to complete it outside of a tutorial?

Yes

No

Other ______

What were the reasons you attempted the MathsFit quiz once only? Please select all that apply.

The feedback email did not suggest a second attempt.

I did not want to complete a second attempt.

I did not have time to complete a second attempt.

I had trouble accessing the second attempt in Brightspace.

I did not know there was a second attempt.

Other ______

How clear was the communication (emails, the video, the Brightspace quiz) about MathsFit?

1 Not at all clear

2

3

4

5 As clear as possible

Did you engage with the MathsFit Refresher course available in Brightspace before your first attempt at the MathsFit quiz?

Yes

No

Other ______

Did you use any of the support suggested in the feedback email you received after completing the MathsFit quiz? It may have suggested you engage with the videos and practice questions in the Refresher course, book a session in the maths support centre and/or join a study group.

No I did not use any of the support suggested. *(Section 5)*

No I did not receive a feedback email. *(Section 6)*

Yes, I engaged with the Refresher Course. *(Section 7)*

Yes, I engaged with the Refresher Course and visited the Maths Support Centre. *(Section 7)*

Yes, I engaged with the Refresher Course, visited the Maths Support Centre and joined a study group. *(Section 7)*

Yes, I visited the Maths Support Centre. *(Section 7)*

Yes, I visited the Maths Support Centre and joined a study group. *(Section 7)*

Yes, I joined a study group. *(Section 7)*

I cannot remember. *(Section 6)*

Other _______ *(Section 6)*

Section 4 (2 or more attempts):

Did you experience technical difficulties while completing the MathsFit quiz? E.g. Numbas freezing, being unable to access all the questions.

Yes

No

How difficult did you find the MathsFit quiz?

1 Very easy

2

3

4

5 Very difficult

How did you feel about your MathsFit quiz result for your first attempt?

1 Very disappointed

2

3

4

5 Very happy

How did you feel about your MathsFit quiz result for your second attempt?

1 Very disappointed

2

3

4

5 Very happy

Your first attempt at the MathsFit quiz was scheduled during your first tutorial while the second attempt was not in a tutorial. Would you have preferred to complete both attempts not in a tutorial?

Yes

No

Other ______

How clear was the communication (emails, the video, the Brightspace quiz) about MathsFit?

1 Not at all clear

2

3

4

5 As clear as possible

Did you engage with the MathsFit Refresher course available in Brightspace before your first attempt at the MathsFit quiz?

Yes

No

Other ______

Would you have liked more structured revision time (for example a tutorial for revision) before attempting the MathsFit quiz for the first time?

Yes

No

Other ______

Did you use any of the support suggested in the feedback email you received after completing the MathsFit quiz for the first time? It may have suggested you engage with the videos and practice questions in the Refresher course, book a session in the maths support centre and/or join a study group.

No I did not use any of the support suggested. *(Section 5)*

No I did not receive a feedback email. *(Section 6)*

Yes, I engaged with the Refresher Course. *(Section 7)*

Yes, I engaged with the Refresher Course and visited the Maths Support Centre. *(Section 7)*

Yes, I engaged with the Refresher Course, visited the Maths Support Centre and joined a study group. *(Section 7)*

Yes, I visited the Maths Support Centre. *(Section 7)*

Yes, I visited the Maths Support Centre and joined a study group. *(Section 7)*

Yes, I joined a study group. *(Section 7)*

I cannot remember. *(Section 6)*

Other _______ *(Section 6)*

Section 5 (did not use the suggested support):

See 2020 version.

Section 6 (did not receive feedback email or could not remember):

See 2020 version.

Section 7 (used suggested support):

See 2020 version.

Final question:

See 2020 version.

2022 version

At the start of trimester, you had the opportunity to participate in MathsFit, a refresher course and proficiency quiz hosted on Brightspace. This short survey asks questions about your experience of MathsFit and maths support in UCD.

What is your student number?

____

How many times did you complete the MathsFit quiz?

0 times – didn't participate. *(Section 2)*

One – just the first attempt. *(Section 3)*

Twice – the first and second attempt. *(Section 4)*

Section 2 (0 attempts):

What were the reasons, if any, you did not participate in MathsFit? Please select all that apply.

Late registration

Did not know about it

Did not want to participate

Lack of internet access

Lack of computer access

Could not find it in Brightspace

Taking a maths quiz in the first week of university made me feel anxious

Other ______

Please rate the clarity of the following MathsFit communications on how to participate:

	Clear	Neutral	Unclear	Did not receive/ watch/attend
Introductory emails in orientation week				
MathsFit Introduction Video				
Information given in your first tutorial				
Feedback email with your quiz results etc.				
MathsFit instructions in Brightspace				
Personal emails with the MathsFit team				

How clearly were the aims of MathsFit communicated?

Clearly

Neutral

Not clearly

Other _____

You may have explored the MathsFit Refresher Course in your first maths tutorial or in your own time. Did you find it useful in terms of refreshing your mathematical skills?

Yes, exploring the Refresher Course was useful.

No, exploring the Refresher Course was not useful.

I did not explore the Refresher Course.

Other _____

If you accessed the MathsFit Refresher Course you will have used Bolster Academy. As part of your maths module's continuous assessment, you also use WeBWorK.

Please rate your agreement with the following statements.

Bolster Academy (MathsFit) is user friendly (easy to navigate, input answers etc).

Strongly agree

Agree

Neutral

Disagree

Strongly disagree

N/A (haven't used)

WebWork is user friendly (easy to navigate, input answers etc).

Strongly agree

Agree

Neutral

Disagree

Strongly disagree

N/A (haven't used)

Are you aware of the Maths Support Centre in UCD? Have you used it before?

No I am not aware of the Maths Support Centre.

Yes I am aware if the Maths Support Centre and have not used it.

Yes I am aware if the Maths Support Centre and have used it.

Which of the following types of maths support, if any, did you use during the last academic year? Please select all that apply.

The UCD Maths Support Centre

MathsFit Refresher Course

Maths module tutors/lecturers

Peers in the same maths module

Family/friends not in the same maths module

Online resources – e.g. YouTube

Other ______

Can you suggest any ways to improve MathsFit?

____

If you would like to explain the reasons for any of your answers or provide any other feedback about MathsFit or maths support at UCD please use this space. All feedback is very welcome.

____

Would you be willing to volunteer for a brief Zoom or in-person interview with PhD student Claire Mullen to discuss your first year university mathematics experience in more depth?

Yes *(Final question)*

No *(End of survey)*

Section 3 (1 Attempt):

How difficult did you find the MathsFit quiz?

1 Very easy

2

3

4

5 Very difficult

How did you feel about your MathsFit quiz result?

1 Very disappointed

2

3

4

5 Very happy

What were the reasons you attempted the MathsFit quiz once only? Please select all that apply.

The feedback email did not suggest a second attempt.

I did not want to complete a second attempt.

I did not have time to complete a second attempt.

I had trouble accessing the second attempt in Brightspace.

I did not know there was a second attempt.

Other ______

You may have explored the MathsFit Refresher Course in your first maths tutorial or in your own time. Did you find it useful in terms of refreshing your mathematical skills?

Yes, exploring the Refresher Course was useful.

No, exploring the Refresher Course was not useful.

I did not explore the Refresher Course.

Other _____

If you accessed the MathsFit Refresher Course you will have used Bolster Academy. As part of your maths module's continuous assessment, you also use WeBWorK.

Please rate your agreement with the following statements.

Bolster Academy (MathsFit) is user friendly (easy to navigate, input answers etc).

Strongly agree

Agree

Neutral

Disagree

Strongly disagree

N/A (haven't used)

WebWork is user friendly (easy to navigate, input answers etc).

Strongly agree

Agree

Neutral

Disagree

Strongly disagree

N/A (haven't used)

Please rate the clarity of the following MathsFit communications on how to participate:

	Clear	Neutral	Unclear	Did not receive/ watch/attend
Introductory emails in orientation week				
MathsFit Introduction Video				
Information given in your first tutorial				
Feedback email with your quiz results etc.				
MathsFit instructions in Brightspace				
Personal emails with the MathsFit team				

How clearly were the aims of MathsFit communicated?

Clearly

Neutral

Not clearly

Other _____

Did you use any of the support suggested in the feedback email you received after completing the MathsFit quiz? It may have suggested you engage with the videos and practice questions in the Refresher course, book a session in the maths support centre and/or join a study group.

No I did not use any of the support suggested. *(Section 5)*

No I did not receive a feedback email. *(Section 6)*

Yes, I engaged with the Refresher Course. *(Section 7)*

Yes, I engaged with the Refresher Course and visited the Maths Support Centre. *(Section 7)*

Yes, I engaged with the Refresher Course, visited the Maths Support Centre and joined a study group. *(Section 7)*

Yes, I visited the Maths Support Centre. *(Section 7)*

Yes, I visited the Maths Support Centre and joined a study group. *(Section 7)*

Yes, I joined a study group. *(Section 7)*

I cannot remember. *(Section 6)*

Other _______ *(Section 6)*

Section 4 (2 attempts):

How difficult did you find the MathsFit quiz?

1 Very easy

2

3

4

5 Very difficult

How did you feel about your MathsFit quiz result for your first attempt?

1 Very disappointed

2

3

4

5 Very happy

How did you feel about your MathsFit quiz result for your second attempt?

1 Very disappointed

2

3

4

5 Very happy

You may have explored the MathsFit Refresher Course in your first maths tutorial or in your own time. Did you find it useful in terms of refreshing your mathematical skills?

Yes, exploring the Refresher Course was useful.

No, exploring the Refresher Course was not useful.

I did not explore the Refresher Course.

Other _____

If you accessed the MathsFit Refresher Course you will have used Bolster Academy. As part of your maths module's continuous assessment, you also use WeBWorK.

Please rate your agreement with the following statements.

Bolster Academy (MathsFit) is user friendly (easy to navigate, input answers etc).

Strongly agree

Agree

Neutral

Disagree

Strongly disagree

N/A (haven't used)

WebWork is user friendly (easy to navigate, input answers etc).

Strongly agree

Agree

Neutral

Disagree

Strongly disagree

N/A (haven't used)

Please rate the clarity of the following MathsFit communications on how to participate:

	Clear	Neutral	Unclear	Did not receive/ watch/attend
Introductory emails in orientation week				
MathsFit Introduction Video				
Information given in your first tutorial				
Feedback email with your quiz results etc.				
MathsFit instructions in Brightspace				
Personal emails with the MathsFit team				

How clearly were the aims of MathsFit communicated?

Clearly

Neutral

Not clearly

Other _____

Did you use any of the support suggested in the feedback email you received after completing the MathsFit quiz? It may have suggested you engage with the videos and practice questions in the Refresher course, book a session in the maths support centre and/or join a study group.

No I did not use any of the support suggested. *(Section 5)*

No I did not receive a feedback email. *(Section 6)*

Yes, I engaged with the Refresher Course. *(Section 7)*

Yes, I engaged with the Refresher Course and visited the Maths Support Centre. *(Section 7)*

Yes, I engaged with the Refresher Course, visited the Maths Support Centre and joined a study group. *(Section 7)*

Yes, I visited the Maths Support Centre. *(Section 7)*

Yes, I visited the Maths Support Centre and joined a study group. *(Section 7)*

Yes, I joined a study group. *(Section 7)*

I cannot remember. *(Section 6)*

Other _______ *(Section 6)*

For Section 5, Section 6, and Section 7:

See 2020 version with the addition of:

Did participating in MathsFit (quiz, refresher course, personalised feedback, support, surveys) affect how prepared you felt for university mathematics?

MathsFit made me feel more prepared.

MathsFit had no impact.

MathsFit made me feel less prepared.

Final question: See 2020 version.

Appendix P: MathsFit Quiz Attempts ANOVA results

Repeated measures ANOVA was calculated for each cohorts' Attempt 1 and Attempt 2 quiz results. The results of these tests are in Table P1.

Table P1: Repeated measures ANOVA for students' MathsFit quiz attempts.

Module	ANOVA
A 2020	$F(1, 9)=20.649$, $p=.001$, $\eta^2_G=0.23$
B 2020	$F(1, 332)=559.513$, $p<.001$, $\eta^2_G=0.209$
A 2021	$F(1, 29)=0.972$, $p=.362$, $\eta^2_G=0.009$
B 2021	$F(1, 234)=61.961$, $p<.001$, $\eta^2_G=0.094$
C 2021	$F(1, 152)=19.836$, $p<.001$, $\eta^2_G=0.046$
D 2021	$F(1, 212)=212$, $p<.001$, $\eta^2_G=0.038$
E 2021	$F(1, 45)=0.0116$, $p<.001$, $\eta^2_G=0.00086$
A 2022	$F(1, 12)=12.484$, $p=.005$, $\eta^2_G=0.051$
B 2022	$F(1, 207)=306.236$, $p<.001$, $\eta^2_G=0.196$
C 2022	$F(1, 212)=229.775$, $p<.001$, $\eta^2_G=0.16$
D 2022	$F(1, 128)=141.663$, $p<.001$, $\eta^2_G=0.208$
E 2022	$F(1, 12)=31.366$ $p<.001$, $\eta^2_G=0.202$

Appendix Q: MathsFit Previous mathematical grade conversion

Table Q1 shows the conversion of all results provided to the nine point scale used in this analysis. Conversions were based on UCD entry requirements (University College Dublin, 2021).

Table Q1: Conversion of participants' previous mathematics examination results.

Education System	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Current LC	O5	O4	H7/O3	H6/O2	H5/O1	H4	H3	H2	H1
Pre-2017 LC	**C3/D1**	**C1/C2**	**B2/B3** E1/E2	**A2/B1** D2/D3	**A1** C3/D1	C1/C2	B2/B3	A2/B1	A1
A-level				E	D	C	B	A	A*
GCSE	5	6	7	8	9				
IB			1	2	3	4	5	6	7
MSAP		50-62	63-75	76-88	89-101	102-114	114-126	127-139	140-150
QQI				Pass		Merit	Distinction		
SAT	1204-1247, 440-479	1248-1291, 480-519	1292-1335, 520-559	1336-1379, 560-599	1380-1423, 600-639	1424-1467, 640-679	1468-1511, 680-719	1512-1555, 720-759	>1556, >760
UCD Access				D+, D, D-	C+, C, C-	B+, B, B-	A-	A	A+
ACT[s]				26-27	28-29	30-31	32-33	34-35	36
Hungarian Malta					3		4		5
AP			1	2	3	3	4	4	5
European B.[t]	1-2	3	4	5	6	7	8	9	10
Czechia Maturita			5		4	3		2	1
Portuguese ENES[u]				10, 11	12, 13	14, 15	16, 17	18	19, 20

Note, the LC grade allocation changed in 2017. While the vast majority of research participants received their LC results post-2017 there was a small number of students who provided their results in the pre-2017 grading system so both are provided. In the row "Pre-2017 LC" grade conversions the bold font indicates Ordinary Level just as the "O"s do in the current LC grading system while non-bold and "H" indicate Higher Level. Advanced Placement (AP) is an American system that allows high school students to take college-level classes. AP in Table 7.2 has 3 and 4

[s] American College Testing

[t] European Baccalaureate

[u] Exames Nacionais do Ensino Secundário or Secondary Education National Exams

repeated as percentage results were provided by students as well as their AP 3, 4, or 5 grade allowing the determination of a "low" 3 (50-59.99%) or a "high" 3 (60-69.99%), a "low" 4 (70-79.99%) or a "high" 4 (80-89.99%).

Twelve other examination systems appeared just once and were not included in the above table as they all translated to a 9 or NA (not available), as students provided the examination but not the result. There were also multiple instances of students selecting "Other" and only providing their result, some were decipherable, others were not and became NA. Some students who selected one of the provided examination systems also provided unconvertable results, for example, LC students provided their CAO points instead of their mathematics grade. In total, there were 213 NAs or unconvertible answers for received results and 58 for expected results. Expected results and received results were converted at the same time and compared to reduce missing conversions as much as possible.

Appendix R: MathsFit Refresher Course changes

With the change in Refresher Course (RC) host in 2022, from Numbas within Brightspace to Bolster Academy a slight change in practice question content occurred. The number of questions and videos per section of the RC for each module in 2021 and 2022 is now outlined.

In 2021, Module A's RC had 53 videos and questions (AT: 8 videos and 8 questions, Algebra: 12 and 9, FC: 8 and 8). Module B's RC had 51 videos and questions (AT: 7 videos and 7 questions, Algebra: 12 and 9, FC: 8 and 8). Module C's RC had 50 videos and questions (AT: 6 and 7, Algebra: 12 and 9, FC: 8 and 8). Both modules D and E's RCs had 61 videos and questions (AT: 10 and 10, Algebra: 11 and 8, FC: 12 and 10).

In 2022, Module A's RC had 256 videos and questions (AT: 8 videos and 69 questions, Algebra: 11 and 146, FC: 8 and 13). Module B's RC had 269 videos and questions (AT: 7 videos and 74 questions, Algebra: 11 and 156, FC: 8 and 13). Module C's RC had 279 videos and questions (AT: 6 and 79, Algebra: 11 and 162, FC: 8 and 13). Modules D's and E's RCs had 295 videos and questions (AT: 10 and 41, Algebra: 11 and 164, FC: 12 and 57). In 2022 there was an increase in the number of practice questions available for students as parts within a topic's exercise were counted as questions. For example, there was a simultaneous equation exercise which had parts a) to e), being five questions. In comparison, the practice questions in 2021 relied on the "Try another question like this" feature in Numbas and had one question per topic.

Appendix S: MathsFit module results correlation and differences analysis

Looking first at correlation analysis, Table S1 presents the correlation between students' final module results and their overall MathsFit quiz percentage result, and the correlation between students' final module results and each quiz section. The number of asterisks represents the significance level, three indicating $p<0.001$, two representing $p<0.01$ and one meaning $p<0.05$.

Table S1: Spearman's correlation between final module results and MathsFit quiz results.

Module	Overall	AT	Algebra	FC
A 2020	0.42***	0.30***	0.36***	0.31***
B 2020	0.55***	0.31***	0.54***	0.45***
A 2021	0.29***	0.16**	0.29***	0.27***
B 2021	0.47***	0.31***	0.45***	0.44***
C 2021	0.44***	0.32***	0.43***	0.33***
D 2021	0.42***	0.32***	0.30***	0.41***
E 2021	0.55***	0.40***	0.48***	0.48***
A 2022	0.52***	0.48***	0.48***	0.43***
B 2022	0.49***	0.26***	0.47***	0.39***
C 2022	0.54***	0.48***	0.45***	0.39***
D 2022	0.48***	0.34***	0.39***	0.31***
E 2022	0.28*	0.04*	-0.04*	0.36*

All correlations were statistically significant and positive, apart from E 2022's Algebra correlation which is significant and negative but very weak. The variety in the strength of the association between the quiz and module assessment results is notable. In particular the weakness of A 2021's overall quiz results (and even the quiz sections) compared to A 2020 and A 2022, and similarly the weakness of E 2022 results compared to E 2021. Comparing the quiz sections correlations, the strongest and weakest quiz sections were not the same for every module. Correlations for each separate part of the modules' assessment, WeBWorK assignments, tutorial quizzes or midterm examinations, and the final examination, were also calculated. These were generally similar, though up to 0.1 weaker than the presented coefficients in Table S1 for the tutorial quizzes or midterm examinations, and the final examinations. The correlation between WeBWorK assignments and the overall quiz and quiz sections percentage results were also about 0.1 weaker than in Table S1, apart from module E in 2021 which had much weaker correlations at 0.19, 0.22, 0.05, and 0.08 for the overall quiz, AT, Algebra, and FC sections respectively. All calculated correlations were statistically significant with $p<.05$, and the majority had $p<.001$.

Spearman's correlation coefficient was not suitable to study the relationship between engagement with the RC and final module results, and visits to the MSC and final module results, as the final module results had a different distribution to the other two variables. Instead, using categories for both the RC and MSC (binary used or not used for the RC, and the four visit categories for the MSC—0, 1, 2–4, and 5+ visits), differences in final module grade were examined via ANOVA or the Kruskal-Wallis test where appropriate. Table S2 presents the results that were statistically significant with the appropriate post-hoc test findings.

Table S2: Differences in MathsFit cohorts' module results when grouped by binary RC use and categorised MSC visits.

Variable	**Module & Year**	**ANOVA/Kruskal result**	**Effect size (ε^2) & C.I.**	**Post hoc test**	**Differences**
RC	B 2020	$F(1)=9.64$, $p=.023$	$\varepsilon^2=0.02$, (0.00, 0.06)	Tukey HSD	Engaged> No engagement
RC	B 2021	$F(1)=9$, $p=.023$	$\varepsilon^2=0.02$, (0.00, 0.05)	Tukey HSD	Engaged> No engagement
RC	C 2021	$F(1)=8.49$, $p=.015$	$\varepsilon^2=0.03$, (0.00, 0.09)	Tukey HSD	Engaged> No engagement
RC	C 2022	$F(1)=9.09$, $p=.023$	$\varepsilon^2=0.03$, (0.00, 0.08)	Tukey HSD	Engaged> No engagement
MSC	B 2020	$F(3)=3.45$, $p=.047$	$\varepsilon^2=0.02$, (0.01, 0.05)	Tukey HSD	0 visits > 5+ visits
MSC	B 2021	$H(3)=12.67$, $p=.029$	$\varepsilon^2=0.03$, (0.01, 0.06)	Dunn	0 visits > 1 visit
MSC	D 2022	$F(3)=3.54$, $p=.044$	$\varepsilon^2=0.05$, (0.02, 0.11)	Tukey HSD	0 visits > 1 visit

Students' module results (transformed to better fit the normal distribution) were analysed for differences due to gender, international status, chosen degree, curriculum coverage, previous grade, and previous exam. The significant differences found are shown in Table S3.

Table S3: Differences in module results when grouped by demographic and previous education factors.

Variable	Module & Year	ANOVA or Kruskal-Wallis	Effect size (ε^2) & C.I.	Post hoc test	Differences
Gender	B 2022	F(1)=5.88, p=.043	ε^2=0.02, (0.00, 0.05)	Tukey HSD	Female > Male
Gender	D 2022	F(1)=5.86, p=.433	ε^2=0.02, (0.00, 0.07)	Tukey HSD	Female > Male
International status	C 2021	H(1)=6.27, p=.034	ε^2=0.02, (0.00, 0.06)	Dunn	International (*n*=24) > Domestic (*n*=234)
International status	D 2021	F(1)=6.38, p=.034	ε^2=0.02, (0.00, 0.07)	Tukey HSD	International (*n*=26) > Domestic (*n*=290)
International status	A 2022	F(1)=7.01, p=0.03	ε^2=0.03, (0.00, 0.07)	Tukey HSD	International (*n*=5) > Domestic (*n*=248)
International status	C 2022	F(1)=14.80, p<.001	ε^2=0.05, (0.01, 0.12)	Tukey HSD	International (*n*=30) > Domestic (*n*=233)
Degree	A 2020	F(11)=3.66, p<.001	ε^2=0.14, (0.10, 0.26)	Tukey HSD	Agricultural Science > Forestry Animal Science-Equine > Forestry Animal Science-Equine > Horticulture, Landscape & Sportsturf Management Food and Agribusiness Management Horticulture > Forestry Food and Agribusiness Management > Landscape & Sportsturf Management Food Science > Forestry
Degree	A 2021	F(12)=2.88, p=.004	ε^2=0.09, (0.07, 0.19)	Tukey HSD	Food Science > Animal Science
Degree	A 2022	F(14)=2.49, p=.011	ε^2= 0.19, (0.14, 0.35)	Tukey HSD	No significant group differences found.
Degree	C 2022	F(5)=4.3, p=.004	ε^2= 0.08, (0.04, 0.16)	Tukey HSD	No preference > BBB
Curriculum	B 2020	F(2)=10.44, p<.001	ε^2= 0.05, (0.02, 0.10)	Tukey HSD	Not Covered > Unsure Covered > Unsure
Curriculum	B 2020	F(2)=10.44, p<.001	ε^2= 0.05, (0.02, 0.10)	Tukey HSD	Not Covered > Unsure Covered > Unsure
Curriculum	B 2021	F(2)=9.72, p<.001	ε^2= 0.04, (0.01, 0.09)	Tukey HSD	Covered > Not Covered Covered > Unsure
Curriculum	B 2022	F(2)=6.32, p=.008	ε^2= 0.03, (0.01, 0.08)	Tukey HSD	Covered > Not Covered
Curriculum	C 2022	F(2)=5.49, p=.016	ε^2= 0.03, (0.01, 0.09)	Tukey HSD	Covered > Not Covered Covered > Unsure
Curriculum	D 2022	F(2)=11.92, p<.001	ε^2= 0.10, (0.04, 0.17)	Tukey HSD	Covered > Not Covered Covered > Unsure

Variable	Module & Year	ANOVA or Kruskal-Wallis	Effect size (ε^2) & C.I.	Post hoc test	Differences
Previous Grade	A 2020	F(8)=3.25, p=.008	ε^2= 0.10, (0.06, 0.21)	Tukey HSD	6>2, 7>2
Previous Grade	B 2020	H(7)=102.23, p<.001	ε^2= 0.23, (0.17, 0.31)	Dunn	8>4, 8>5, 8>6, 8>7, 9>4, 9>5, 9>6, 9>7
Previous Grade	A 2021	H(8)=49.57, p<.001	ε^2= 0.148, (0.10, 0.23)	Dunn	7>1, 8>1, 8>2, 8>3, 8>4, 8>5, 8>6, 9>1, 9>2, 9>3, 9>4, 9>5, 9>6, 9>7
Previous Grade	B 2021	F(7)=16.98, p<.001	ε^2= 0.21, (0.15, 0.29)	Tukey HSD	8>4, 9>4, 8>5, 9>5, 8>6, 9>6, 8>7, 9>7, 9>8
Previous Grade	C 2021	F(7)=9.36, p<.001	ε^2= 0.21, (0.14, 0.33)	Tukey HSD	8>4, 9>4, 8>5, 9>5, 8>7, 9>7
Previous Grade	D 2021	F(4)=18.63, p<.001	ε^2= 0.19, (0.12, 0.27)	Tukey HSD	5>6, 5>7, 5>8, 9>6, 9>7, 9>8
Previous Grade	A 2022	F(8)=16.48, p<.001	ε^2= 0.47, (0.37, 0.59)	Tukey HSD	5>1, 6>1, 7>1, 8>1, 9>1, 7>2, 8>2, 9>2, 6>3, 7>3, 8>3, 9>3, 6>4, 7>4, 8>4, 9>4, 7>5, 8>5, 8>6, 8>7
Previous Grade	B 2022	F(7)=25.06, p<.001	ε^2= 0.30, (0.24, 0.38)	Tukey HSD	9>3, 8>4, 9>4, 8>5, 9>5, 8>6, 9>6, 8>7, 9>7, 9>8
Previous Grade	C 2022	F(7)=15.49, p<.001	ε^2= 0.28, (0.20, 0.39)	Tukey HSD	9>3, 9>4, 8>5, 9>5, 9>6, 8>7, 9>7, 9>8
Previous Grade	D 2022	F(4)=14.62, p<.001	ε^2= 0.20, (0.13, 0.29)	Tukey HSD	9>6, 9>7, 9>8
Previous Exam	B 2020	F(5)=8.74, p<.001	ε^2= 0.07, (0.04, 0.13)	Tukey HSD	A-levels > GSCEs A-levels > QQI IB > QQI LC > QQI Other > QQI
Previous Exam	A 2021	F(7)=3.02, p=0.014	ε^2= 0.05, (0.02, 0.11)	Tukey HSD	Other > IB
Previous Exam	B 2021	H(6)=34.8, p<.001	ε^2= 0.076, (0.05, 0.13)	Dunn	A-levels > QQI LC > QQI
Previous Exam	C 2021	F(6)=2.7, p=0.042	ε^2= 0.04, (0.01, 0.11)	Tukey HSD	No significant differences found.
Previous Exam	B 2022	H(7)=29.8, p<.001	ε^2= 0.07, (0.04, 0.13)	Dunn	A-levels > LC A-levels > QQI A-levels > SATs Other > QQI
Previous Exam	C 2022	F(8)=6.31, p<.001	ε^2= 0.15, (0.09, 0.25)	Tukey HSD	A-levels > QQI IB > QQI Other > LC LC > QQI Other > QQI