# THE GROWTH, EMBEDDING, EVOLUTION AND SUSTAINABILITY OF MATHEMATICS SUPPORT WITHIN HIGHER EDUCATION

By

Michael James Grove

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School of Mathematics
College of Engineering and Physical Sciences
University of Birmingham
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# Synopsis

For almost 25 years evidence has existed of a 'mathematics problem' within UK higher education. The work contained herein is concerned with the author's long-standing interest and research into this problem and the subsequent response of UK higher education institutions. Mathematics support forms an important means of assisting students in all disciplines, and at all levels, with their mathematical learning. Whilst there previously existed evidence of its impact upon learners, there existed little evidence of its evolution within institutions or its likelihood of becoming a sustainable part of institutional provision. The research presented here demonstrates the growth of mathematics support within UK higher education and the value institutions now place upon it in assisting their learners. It shows their continued investment in the provision, and through the application of newly developed approaches to evidencing sustainability, how the sustainability of mathematics support has been assured through evolution in its delivery to become a core institutional service. The research demonstrates the powerful enhancement role that mathematics support, and approaches derived from it, can have in supporting the specialist and more-able mathematics student, and its role in aiding the development of those who work as tutors through the communities that develop within it.

# Acknowledgements

The work described within this thesis has been developed over a period of 15 years and during this time I have been very fortunate to work with many different colleagues from across the higher education sector. In particular I would like to thank: Professor Tony Croft, Professor Duncan Lawson and Professor Mike McLinden for not only our very productive and enjoyable collaborations but also their continued support and expert guidance in helping to prepare this submission; Drs Joe and Dee Kyle for many helpful conversations and for their feedback on the various draft versions of this thesis; and, Professor Jon Green for being so willing to act as my Advisor and for guiding me through the submission and examination process. I am also indebted to the late Professor John Blake who provided the inspiration, influence and motivation upon which my career has been based.

Finally, I would like to thank my parents, Pat and Barry, for ensuring that I had access to all of the opportunities throughout my life that have made the submission of this thesis possible.

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# List of Published Works

## Notes

Published works have been divided into two lists:

- Works included within **List A** represent those where the author has had a leading and promiment role in the development and execution of the research and activities described and in the writing of the published output. Within the Review Commentary published works from List A are <u>underlined</u> and highlighted in **bold** (i.e. <u>**Grove (XXXX)**</u>).
- Works included in **List B** are further works by the author that give useful context to the overall body of work in List A or those where the author has made an important but not leading contribution. Within the Review Commentary published works from List B are highlighted in **bold** only (i.e. **Grove (XXXX)**).

## List A: Works Submitted for Consideration

| Number | Reference | Nature |
|---|---|---|
| A1. | Lawson, D.A., **Grove, M.J.** & Croft, A.C. (2019). The evolution of mathematics support: a literature review. *International Journal of Mathematical Education in Science and Technology*. Advance online publication https://doi.org/10.1080/0020739X.2019.1662120 | Peer Reviewed Journal Article |
| A2. | **Grove, M.J.**, Mac an Bhaird, C. & O'Sullivan, C. (2019). Professional development opportunities for tutors of mathematics learning support. *MSOR Connections*, 18(1), pp. 4-15. | Peer Reviewed Journal Article |
| A3. | **Grove, M.J.** & Good, C. (2019). Approaches to feedback in the mathematical sciences: just what do students really think? *Teaching Mathematics and its Applications*. Advance online publication https://doi.org/10.1093/teamat/hrz013 | Peer Reviewed Journal Article |
| A4. | **Grove, M.J.**, Croft, A.C. & Lawson, D.A. (2019). The extent and uptake of mathematics support in higher education: results from the 2018 survey. *Teaching Mathematics and its Applications.* Advance online publication https://doi.org/10.1093/teamat/hrz009 | Peer Reviewed Journal Article |
| A5. | **Grove, M.J.**, Guiry, S. & Croft, A.C. (2019). Specialist and more-able mathematics students: understanding their engagement with mathematics support. *International* | Peer Reviewed Journal Article |

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|---|---|---|
| | *Journal of Mathematical Education in Science and Technology*. Advance online publication https://doi.org/10.1080/0020739X.2019.1603407 | |
| A6. | **Grove, M. J.**, Croft, A. C., Lawson, D. A. & Petrie, M. (2019). Community perspectives of mathematics and statistics support in higher education: The role of the staff member. *Teaching Mathematics and its Applications*, 38(1), pp. 43-59. | Peer Reviewed Journal Article |
| A7. | **Grove, M.J.** & Croft, A.C. (2019). Learning to be a postgraduate tutor in a mathematics support centre. *International Journal of Research in Undergraduate Mathematics Education*, 5(2), pp. 228-266 | Peer Reviewed Journal Article |
| A8. | McLinden, M.T., **Grove, M.J.**, Green, J.R. & Birch, A. (2019). Developing and embedding inclusive policy and practice within higher education institutions. In Krčmář, K. (Ed.), *The Inclusivity Gap* (pp. 160-176). Aberdeen, UK: Inspired By Learning. | Invited Book Chapter |
| A9. | **Grove, M. J.**, Croft, A. C., Lawson, D. A. & Petrie, M. (2018). Community perspectives of mathematics and statistics support in higher education: building the infrastructure. *Teaching Mathematics and its Applications*, 37(4), pp. 171-191. | Peer Reviewed Journal Article |
| A10. | **Grove, M. J.** & Pugh, S. L. (2017). Defining 'sustainability indicators' for higher education teaching and learning innovations. *Education in Practice*, 3, pp. 13-18. | Peer Reviewed Journal Article |

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|---|---|---|
| A11. | Croft, A.C, **Grove, M.J.** & Lawson, D.A. (2016). The oversight of mathematics, statistics and numeracy support provision at university level - A guide for Pro-Vice-Chancellors. Loughborough, UK: sigma. | Published Guide |
| A12. | Croft, A. C. & **Grove, M. J.** (2016). Mathematics and statistics support centres: Resources for training postgraduates and others who work in them. *MSOR Connections,* 14(3), pp. 3-13. | Peer Reviewed Journal Article |
| A13. | Croft, A. C., Lawson, D. A., Hawkes, T. O., **Grove, M. J.**, Bowers, D. & Petrie, M. (2015). sigma – a network working! *Mathematics Today*, 51, 36-40. | General Interest Publication |
| A14. | **Grove, M.J.** & Pugh, S.L. (2015). Is a conceptual understanding of maths vital for chemistry? *Education in Chemistry*, 52(1), pp. 26-29. | Online Magazine |
| A15. | Croft, A.C. & **Grove, M.J.** (2015). Progression within mathematics degree programmes. In Grove M. J., Croft A. C., Kyle J. & Lawson D. A. (Eds.), *Transitions in Undergraduate Mathematics Education* (pp. 173-190). Birmingham, UK: University of Birmingham and Higher Education Academy. | Edited Book Chapter |
| A16. | Savage, M.D. & **Grove, M.J.** (2015). Mathematical modelling and problem solving: High-level skills for higher education STEM students. In Grove, M.J., Croft, A.C., Kyle, J. and Lawson, D.A. (Eds.) *Transitions in undergraduate* | Edited Book Chapter |

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| | *Mathematics Education* (pp.). Birmingham, UK: University of Birmingham and Higher Education Academy. | |
| A17. | **Grove, M.J.** & Kyle, J. (2014). Enquiry into Learning and Teaching in Mathematics and Engineering. In Cleaver, E., Lintern, M., McLinden, M. (Eds.), *Teaching and Learning in Higher Education: Disciplinary Approaches to Educational Enquiry* (pp.126-145). London, UK: SAGE. | Invited Book Chapter |
| A18. | McLinden, M.T., **Grove, M.J.**, Green, J.R. & Birch, A. (2014). Developing and embedding inclusive policy and practice within the University of Birmingham. *Education in Practice*, 1(1), pp. 18-21. | Peer Reviewed Journal Article |
| A19. | **Grove, M.J** (2013a). 'Sustainability of Programme Outcomes' in Grove, M.J. *National HE STEM Programme – Final Report.* Birmingham, UK: University of Birmingham, pp. 177-212. ISBN 978-1-909557-01-7. Available at https://www.birmingham.ac.uk/Documents/college-eps/college/stem/national-he-stem-programme-final-report.pdf | Published Report |
| A20. | **Grove, M.J.** (2012b). The Mathematical Transition: A Multi-Stage Problem? *MSOR Connections*, 12(1), pp. 15-18. | Peer Reviewed Journal Article |
| A21. | **Grove, M.J.** (2012a). *An Impact Framework Approach to Project Level Evaluation*. In: *Evaluating your HE STEM Project or Activity* (pp. 8-11). Birmingham, UK: National HE STEM Programme. ISBN 978-0-9567255-4-7. Available at | Article within Published Guide |

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| | https://www.birmingham.ac.uk/Documents/college-eps/college/stem/evaluating-your-hestem-project-final.pdf | |
| A22. | Croft, A.C., **Grove, M.J.** & Bright, D. (2008). A resource and activity centre for mathematics students beyond their transition to higher education. *MSOR Connections,* 8(1), pp. 11-16. | Peer Reviewed Journal Article |
| A23. | **Grove, M.J.** & Lawson, D.A. (2006). Increasing the Supply of Mathematical Sciences Graduates A Community-wide Programme of Activity. *MSOR Connections*, 6(4), pp. 3-8. | Peer Reviewed Journal Article |
| A24. | Hibberd, S. & **Grove, M.J.** (2006). A Response to the Royal Society paper: Science Higher Education in 2015 and beyond – call for evidence. *MSOR Connections*, 6(3), pp. 1-4. | Peer Reviewed Journal Article |
| A25. | Croft, A.C. & **Grove, M.J.** (2006). Mathematics Support - Support for the specialist mathematician and the more able student. *MSOR Connections*, 6(2), pp. 1-5. | Peer Reviewed Journal Article |
| A26. | **Grove, M.J.**, Kyle, J. & Cox, W. (2006). The weakest link? Supporting the postgraduate teaching assistant. In D. Corcoran & S. Breen (Eds.), *Proceedings of second international science and mathematics education conference* (pp. 116-123). Dublin: St Patrick's College, Drumcondra, Dublin. | Reviewed Conference Proceedings |

## List B: Works Listed for Information

| Number | Reference | Nature |
|---|---|---|
| B1. | **Grove, M.J.** & Overton, T.L. (Editors) (2013). *Getting Started in Pedagogic Research within the STEM Disciplines*. Birmingham, UK: University of Birmingham & The Higher Education Academy. ISBN 978-1-909557-05-5. Available at https://www.birmingham.ac.uk/Documents/college-eps/college/stem/getting-started-in-stem-pedagogic-optimised.pdf | Published Guide |
| B2. | **Grove, M.J** (2013b). *National HE STEM Programme – Final Report.* Birmingham, UK: University of Birmingham. ISBN 978-1-909557-01-7. Available at https://www.birmingham.ac.uk/Documents/college-eps/college/stem/national-he-stem-programme-final-report.pdf | Published Report |
| B3. | Croft, A.C. & **Grove, M.J.** (Eds.) (2011). *Tutoring in a Mathematics Support Centre: A Guide for Postgraduate Students*. Loughborough, UK: National HE STEM Programme & sigma. ISBN: 978-0-9567255-3-0. Available at http://www.mathcentre.ac.uk/resources/uploaded/46836-tutoring-in-msc-web.pdf | Published Guide |
| B4. | Marr, C.M. & **Grove, M.J.** (Eds.) (2010). *Responding to the Mathematics Problem.* Birmingham, UK: Higher Education Academy Maths, Stats & OR Network & the University of St | Edited Conference Proceedings |

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|---|---|---|
| | Andrews. ISBN 978-0-9555914-6-4. Available at http://www.mathcentre.ac.uk/resources/uploaded/mathssupportvolumefinal.pdf | |
| B5. | Hibberd, S. & **Grove, M.J.** (2009). Developing graduate and employability skills within a mathematical sciences programme. *MSOR Connections*, 9(2), pp. 33-39. Available at https://www.heacademy.ac.uk/system/files/msor.9.2l.pdf | Peer Reviewed Journal Article |
| B6. | Mackenzie, H., Tolley, H., Croft, A.C., **Grove, M.J.** & Lawson, D.A. (2016). Senior management perspectives of mathematics and statistics support in higher education: moving to an 'ecological' approach. *Journal of Higher Education Policy and Management*, 38(5), pp. 550-561. | Peer Reviewed Journal Article |

# Critical Review

## 1. Introduction

For almost 25 years evidence has existed of the challenges experienced by UK engineering, physics and mathematics undergraduates as a result of their lack of preparedness for the mathematical components of their university studies (Sutherland & Pozzi, 1995; LMS, IMA & RSS, 1995; Hawkes & Savage, 2000). Whilst this so called 'mathematics problem' may have had its origins in the science, technology, engineering and mathematics (STEM) disciplines, more recent reports have highlighted that many other students are arriving in higher education mathematically underprepared for their studies and have noted the impacts upon both students and higher education staff, in a range of disciplines. For example, in the discipline of chemistry, where the 'mathematics problem' had not previously been well studied, **Grove & Pugh (2015;p.27)** determined that "*the mathematics problem manifests across all areas of chemistry, particularly in relation to the skills required to support practical work*". In particular they argue that this problem is not necessarily due to students studying an insufficient amount of mathematics prior to university entry, but rather is due to its importance not continually being reinforced throughout the pre-university and undergraduate chemistry curriculum. By drawing together a range of national reports and studies, **Lawson, Grove & Croft (2019)** provide a detailed overview of the key issues now identified with student learning of mathematics in a range of discipline areas. They identify issues in diverse discipline areas including the arts, humanities, health and social sciences as these subjects have become increasingly quantitative.

One response to help mitigate the mathematical issues and challenges experienced by students in higher education has been the establishment of mathematics support. As noted by Lawson, Croft & Halpin (2003;p.9) mathematics support is a "*facility offered to students…which is in addition to their regular programme of teaching, lectures, tutorials, seminars, problems classes, personal tutorials, etc.*"; that is, it does not form part of the core or compulsory curriculum of the programme that the student is studying. **Marr & Grove (2010)** demonstrate how mathematics support can be offered to students in a range of different forms including on a drop-in or appointment basis in small groups or one-to-one, with a now widely adopted approach being that of a mathematics support centre that students can visit to receive help with their mathematical learning. However, as **Lawson, Grove & Croft (2019;p.26)** highlight within their review of the literature, "*mathematics support has rapidly evolved*" and in particular "*it has evolved from being a remedial service to being about enabling enhancement of learning for all students*", including the specialist and more-able mathematics student (**Grove, Guiry & Croft, 2019**), with provision now widely available to, and accessed by, a range of learners **(Grove, Croft & Lawson, 2019)**. There is now a significant body of evidence detailing its effectiveness on student retention and progression (Matthews et al., 2013; **Lawson, Grove & Croft, 2019**).

The evolution of mathematics support within higher education coincides with the development of a strong community of practice in this area (**Croft et al., 2015**) and as Kyle (2010;p.103) notes, "*Mathematics support came of age in the first decade of the 21st century. What might once have been described as a cottage industry now plays a respected and widely adopted role in Higher Education.*"

## 2. Aims of the Research

The aim of the research described in this narrative, and which forms the basis of the case being made by the author for the award of PhD by Published Work, was to develop, and apply within the UK, a methodology for exploring the sustainability of teaching and learning enhancements and innovations within higher education with a particular emphasis upon mathematics support. The work described here applied methodologies and findings derived from earlier research by the author to explore the ways in which the development, delivery and impact of mathematics support within UK higher education has grown and evolved. In doing so it has investigated the extent to which mathematics support has now become firmly embedded within the provision and practice of higher education institutions and has enabled judgements to be made on its potential for longer-term sustainability.

In particular the work contained here explored, over 13 years, the following research themes:

1. Approaches for identifying the likelihood for sustainability of learning and teaching interventions within UK higher education within the STEM disciplines.
2. Mechanisms for the evaluation of mathematics support with an emphasis upon its longer-term potential for sustainability.
3. The growth and sustainability of mathematics support and its impact upon the provision and practice of higher education institutions.
4. The role of individuals in the provision of mathematics support, including the experiences and training needs of those who work as tutors and the role of communities and community structures.
5. The important, and transferable role, of mathematics support in supporting the specialist and more-able mathematics student, i.e. users who did not originally form part of its intended user base.

In total 26 authored and co-authored works are presented here for consideration (List A), along with a further six that are referenced for information (List B). These published works adopt a range of different research methodologies. They include surveys, both at a large scale (UK national) and more localised (institutional), with both quantitative and qualitative analyses of their results and findings. Other works are fully qualitative in nature and arise from structured interviews, thematic reviews of the published literature, or the structured analysis of reports, case studies and other documentation emerging from national (UK) projects and activities.

The career of the author within UK higher education has, in itself, evolved over the last 15 years, and the range of works presented here reflect this evolution. Whilst several initial works explore the challenge encountered by students in relation to their learning of mathematics, others reflect the role of the author in establishing and leading national programmes of activity, including *MoreMathsGrads* and the National HE STEM Programme, and the research that emerged from it, to increase participation within the STEM disciplines and enhance the way in which institutions deliver their curricula. Following the completion of the National HE STEM Programme, of which mathematics support and teaching enhancement within the mathematical sciences were important components, the transition to an academic career meant the author was increasingly able to return to his earlier work of responding to the challenges posed by the 'mathematics problem' within UK higher education. Overall the published works demonstrate how the author has built upon research and scholarship within his early career by adapting the research approaches, methodologies and frameworks, and then applying these to study the growth, embedding, evolution and sustainability of mathematics support within UK higher education.

## 3. Significance of the Research

The work that will now be described offers new research insight in a number of areas:

1. The development and application of a framework for assessing the sustainability potential of higher education teaching and learning interventions within the STEM disciplines.

2. The development of a framework for exploring progress towards changed institutional practice within higher education.
3. Identifies how the development and delivery of mathematics support has evolved within higher education institutions, and how its sustainability appears assured through it becoming an increasingly valued and embedded part of institutional provision and practice.
4. Demonstrates how the sustainability of mathematics support is evident through the practices and values of the individuals who work within it. It shows the important role that postgraduates have in providing this support, the challenges they face, and how working in a mathematics support environment contributes to their personal and professional aspirations and development. In particular it demonstrates the importance of a 'community' amongst those working in mathematics support.
5. Shows the extensive use made of mathematics support by a diverse range of users, and its evolution from what might have originally been considered a 'remedial' service to one that now also encompasses 'enhancement'.
6. Highlights how the features of mathematics support known to be most valued by learners can become embedded within departmental practices, and as such shows the powerful potential for mathematics support to influence more mainstream teaching and learning practice.

## 4. Background: Large-scale Programmes of Activity

The term the 'mathematics problem' was first introduced in a joint LMS, IMA & RSS (1995) report and described the lack of technical fluency, skills in problem solving, and understanding of the rigorous nature of mathematics amongst students commencing their undergraduate studies in mathematics, engineering and the physical sciences. However, while this problem was manifesting itself in the challenges faced by the staff tasked with teaching these newly starting students, particularly in terms of high drop out and failure rates, a wider issue of low enrolment in courses with A-level mathematics entry requirements was affecting the recruitment of students to engineering and the physical sciences by universities (Beveridge & Bhanot, 1994). For mathematics in particular the situation was stark: between 1998 and 2004 the overall number of full-time UK and EU starters studying the mathematical sciences within the UK fell by almost 13%, and for particular student groups, for example female students, the unpopularity of the mathematical sciences was particularly marked (**Grove & Lawson, 2006**).

Some of those staff working to tackle the issues associated with the lack of mathematical skills, knowledge and fluency of students within UK higher education began to develop the concept of mathematics support. In parallel there became a fundamental need to address the national decline in participation within the mathematical sciences at university level. In 2004 the *MoreMathsGrads* initiative was established forming a £3.3 million pilot programme of activity designed to increase and widen participation within the mathematical sciences. In addition to themes of activity that were designed to help school and college students gain, and then sustain, their interest in the mathematical sciences with a view to encouraging them to pursue its further study, an additional focus of this project included work "*to explore the learning, teaching and assessment methods in university mathematical sciences departments to determine if changes might be made to better support students throughout their studies*" (**Grove & Lawson, 2006;p.7**). This strand of work comprised a comprehensive review across all aspects of the undergraduate curriculum, and whilst a full summary of the research and findings that emerged from it can be found within Robinson, Thomlinson & Challis (2010), one of their recommendations for supporting students with their learning of mathematics at the transition to university called for the establishment of mathematics support centres within institutions where they did not currently exist.

*More Maths Grads* formed one of four disciplinary pilot projects, the others were in chemistry, engineering and physics, initiated by the (then) Higher Education Funding Council for England (HEFCE). Upon the conclusion of these individual projects in July 2009, HEFCE established a larger and integrated three-year programme of activity, the £21million National HE STEM Programme, to build upon the work of the pilot projects and initiate new programmes of activity both within, and across, the four STEM disciplines that it represented within England and Wales. Described in detail in **Grove (2013;§2)**, the Programme was set a challenging remit. It needed to integrate the four previously successful pilot projects and embed their activities firmly within the practices of higher education institutions. At the same time, it needed to maintain focus upon widening and supporting participation in higher education and take forward a new agenda relating to higher level skills. The need for activity within the mathematical sciences community to ensure its graduates possessed the necessary skills, abilities and experience to successfully make the transition to the workplace had previously been argued by **Hibberd & Grove (2006)**, along with the identification of strategies and examples of good practice as to how this might be successfully achieved (**Hibberd & Grove, 2009**). Significantly, all practices and approaches developed through the Programme had a requirement, as judged by HEFCE, to be sustainable such that they might continue within the higher education sector after its conclusion, although at the time, no methodology existed for exploring their sustainability potential.

Mathematics support formed a dedicated strand of activity within the National HE STEM Programme with its work led by the **sigma** Centre for Excellence in University-wide Mathematics and Statistics Support based at Loughborough and Coventry Universities. Over its three-year duration, a national network, comprised of regional hubs of mathematics support practitioners was established across England and Wales, along with the creation of 22 new mathematics support centres through the provision of funding and direct mentoring (**Croft et al., 2015**). In 2013, with the endorsement of the Minister of State for Universities and Science (Willetts, 2013), HEFCE provided additional funding to the now-named **sigma** Network to establish a three-year follow-on programme of activity to maintain, and further embed, mathematics and statistics support across English higher education institutions. Whereas the previous work of **sigma** had focused upon supporting practitioners, an additional focus for its future work was to explore the high-level sector needs in relation to mathematics and statistics support, including how it might work with senior management within universities to ensure its provision met institutional needs in a sustainable manner.

The importance of these activities, and the networks, which now exist within England and Wales, Scotland and Ireland, established around them, cannot be overstated. As **Grove (2013;p.9)** identified within the context of the National HE STEM Programme "*engaging with existing networks and communities offered real added value to the work of the Programme and the potential to embed and enhance its activities*". It is through the network established by **sigma** that a means to investigate the role and positioning of mathematics support within the higher education sector has been possible, and this has contributed directly to the research work that is now described.

## 5. The Development of Frameworks for Assessing Sustainability

The National HE STEM Programme offered a legacy of learning that influenced subsequent approaches towards the development, delivery and evaluation of mathematics support. The Programme was required to establish mechanisms to identify particularly successful approaches and then transfer these between institutions so that they could be adopted more widely. Given its scale, if the legacy and learning of the Programme were to be captured, then it would be necessary for project leads to effectively evaluate and disseminate the impact of their endeavours for themselves. As a consequence, a structured series of activities initiated by the author to help project leads evaluate their own work or begin researching the impact of their interventions commenced (**Grove & Overton, 2013**).

The approach adopted by the Programme was practical and had an emphasis upon demonstrating how existing disciplinary skills might be adapted to enable educational research or enquiry. **Grove & Kyle (2014)** argue that an approach to educational enquiry in mathematics and engineering might mirror the way in which mathematicians and engineers tackle problems through the disciplinary mathematical modelling and problem solving cycle. As such, making the transition to educational research within the context of a STEM discipline may not be as daunting as it might at first seem since individuals have a wide range of relevant knowledge and skills upon which they can draw and apply, particularly if they approach this activity in collaboration with others. A range of resources was developed by the author to aid project leads in this process and to provide opportunities for individuals to work together on the development of evaluative methodologies. For example, **Grove (2012a)** describes a practical impact-based framework consisting of a hierarchical series of indicators against which those undertaking educational enhancement activities should consider collecting evidence during their work; **Grove and Overton (2013),** a resource produced following a series of workshops and events, provides an accessible introduction to educational research along with a practical guide containing hints and tips on how individuals may get started. By engaging individual project leads in this process, it was intended to help enhance the quality of the evidence presented in their reports of the impact and sustainability of their work, and in doing so enhance the ability of the author to use these as part of a research project based around the sustainability of these interventions.

A key priority throughout the Programme was one of sustainability (**<u>Grove, 2013a</u>**), that is the extent to which its individual activities would continue after it concluded. Whilst there had previously been consideration of the sustainability of interventions within healthcare settings (see for example Stirman et al. (2012) who review the published literature), the author, through his leadership of the Programme, was the first to make this an explicit focus for educational interventions. From his own research, involving the analysis of themes emerging from the individual case studies and reports, and latterly commissioned reviews of strands of activity (see for example Tolley, Greatbatch & Mackenzie, 2013), the author was able to define, apply and evaluate a framework for reviewing whether educational interventions are likely to have the potential for longer-term sustainability.

The author's 'Sustainability Framework' was first developed as part of an internal, and unpublished, review at the mid-term point of the National HE STEM Programme. It defines a series of ten 'sustainability indicators' that, if observed, are likely to contribute to an activity being sustainable in the longer term and which may therefore be used to make a reasoned and evidence-based judgement relating to its longer-term potential for sustainability. **<u>Grove (2013)</u>** presents a detailed discussion of each indicator along with an analysis of the available evidence obtained through research undertaken during the Programme. In evaluating the effectiveness of his framework **<u>Grove (2013;p.185)</u>** concludes that the *"analysis indicates that not only do these ten factors remain valid, but when completed projects…were revisited, they appear to function as reasonable indicators of the sustainability potential…beyond the end of a funding period*." Whilst similarities exist with the work of Scheirer (2013), who proposes a framework for analysing the sustainability of interventions within a healthcare context, their work is based around more theoretical arguments. The ease of application of any framework by others is important and a generic version of the 'Sustainability Framework', stripped of its context within the National HE STEM Programme, was latterly developed by **Grove & Pugh (2017)**; this work also incorporates practical guidance on how each of the ten indicators might be interrogated or evidenced by others.

The 'Sustainability Framework' gives an indication of the potential for sustainability for an activity, that is the likelihood it will continue after a particular project has ended. However, it is unable to offer insight into the extent to which individual activities might themselves become embedded as part of the core provision or practice of an institution. A more robust longer-term measure of the impact and sustainability of an activity, and indeed its embedding, is the way in which it brings about genuine change to the culture and operation of the hosting organisation. When considering work to establish an inclusive curriculum, that is a curriculum that "*takes into account students' educational, cultural and social background and experience as well as the presence of any physical or sensory impairment and their mental well-being*" (Morgan & Houghton, 2011;p.5), the author and his collaborators (**McLinden et al., 2014)** present the outline of an innovative data collection methodology for exploring progress towards genuine institutional change. The approach adopted towards establishing a wholly inclusive curriculum was based around one of appreciative inquiry, a methodology that seeks to engage stakeholders in self-determined change (Cooperrider & Srivastva, 1987), with individuals participating in a working group drawn from across the institution. With change being driven by the individuals themselves, data collection was able to draw upon a practical approach to educational enquiry similar to that defined by the author within **Grove & Kyle (2014)** to monitor and evidence progress towards this change. Particularly innovative in this work is the adaptation of the McKinsey 7S organisational change framework (Pascale & Athos, 1981), widely used within business and industry but not previously known to have been used within higher education, to establish an evidence baseline and monitor potential change across the institution.

**McLinden et al. (2014)** presents a practical version of their developed framework, describing how the McKinsey 7S framework might be adopted and used for evidencing institutional change, and includes examples of evidence sources and potential success measures. The author's follow-up work (**McLinden et al., 2019**) draws upon the experience and lessons learned from its implementation in the context of establishing an inclusive curriculum. In doing so it identifies several challenges in evidencing institutional change that resonate with those encountered during the National HE STEM programme. These include "*the need to ensure that flexible and practical evaluation approaches are built in from the beginning of any change initiative*" (**McLinden et al., 2019;p.172**) and more broadly challenges associated with not only ascertaining the impact of the activities upon learners but also the timescales in which impact and sustainability can be observed and documented (**Grove, 2013a**).

As shall now be described, these frameworks developed by the author and his collaborators were latterly used, for the first time, to assess the embedding and sustainability of the mathematics support provision that has grown and developed within UK higher education.

## 6. The Growth and Sustainability of Mathematics Support Within Institutions

The reasons why students from across a very broad spectrum of courses and at all levels of their university study engage with mathematics support are multi-faceted and complex. For example, Williams (2015), in respect of the STEM disciplines, highlights the mis-match between university teaching and learning approaches and student expectations. Solomon and Croft (2016) report upon how different students of the mathematical sciences find the relationship they have with mathematics between university and school; within other disciplines some students "*show a lack of even basic mathematical skills*" (ABPI, 2008;p.14). As shall be seen, **Grove, Guiry & Croft (2019)** explore why specialist and more-able mathematics students choose to utilise mathematics support. **Grove, Croft & Lawson (2019)** discuss further both the users and non-users of mathematics support and their reasons for doing so.

The growth of mathematics support, that is the number of institutions offering some form of provision, within UK higher education is now well documented in publications by the author and his collaborators. **Grove, Croft & Lawson (2019)** contains a summary of previous surveys and demonstrates that from the first survey in 2000 (Lawson et al., 2002), to their most recent survey in 2018, there has been significant growth in the proportion of institutions offering mathematics support. Significantly the work of **Grove, Croft & Lawson (2019)** draws together other national surveys to present a perspective of mathematics support across the UK and Ireland; it shows that out of 161 contacted institutions, 75% made some form of mathematics support provision available to learners, and amongst those who responded (135), 86% offered mathematics support.

In addition to the wide availability of provision there is a growing body of research demonstrating the positive impact mathematics support has upon student performance, retention, satisfaction and confidence. Matthews et al. (2013) undertook the first comprehensive review of the published literature relating to the effectiveness of mathematics support that existed up until the end of 2012. The more recent review of the author (**Lawson, Grove & Croft, 2019)**, and indeed most comprehensive to date, builds upon that of Matthews et al. (2013) and summarises a further series of works, published from 2013 onwards, that contain additional evidence of the impact of mathematics support upon learners. Perhaps the most compelling evidence for the important role of mathematics support in supporting student learning comes from O'Sullivan et al. (2014) because as **Lawson, Grove & Croft (2019;p.25)** note their "*seminal large-scale evaluation in Ireland produced the very powerful datum that 63% of mathematics support users who had considered dropping out of university felt that the availability of mathematics learning support had influenced their decision to continue with their studies*".

Whilst there existed a growing body of evidence of the impact of mathematics support upon students and their learning, there was little exploring its value from an institutional perspective, that is the role and value placed upon it in contributing to the aims and objectives of the institution as judged by senior management. As the framework of **Grove & Pugh (2017)** highlights, activities have their greatest potential for sustainability if they align with the priorities of an institution, they benefit from institutional commitment, and offer the potential to impact upon its wider work and mission. Further, within the adapted McKinsey 7S framework of **McLinden et al. (2014)** changes to 'Strategy' and institutional 'Structures' are important indicators of progress towards genuine organisational change. At a more practical level, the provision of mathematics support, an additional service for learners, often requires both a level of financial resource from within the institution along with a 'champion' or leader for the provision to remain viable as Perkin, Croft & Lawson (2013;p.171) note when analysing the results of their 2012 survey: "*At a small number of institutions provision has ceased or been reduced—this seems, in the main, to relate to lack of available funds or lack of strategic leadership rather than because the need for such support has disappeared.*"

Within the National HE STEM Programme there existed emerging evidence that higher education institutions were strategically investing in their mathematics support provision. **Grove (2013b)** analysed the Office For Fair Access (OFFA) and Welsh Fee Plan Agreements, statements submitted by higher institutions to their funding bodies that made explicit commitments as to how they would work to increase and widen participation and support learners upon arrival at university, and noted four references to mathematics support from institutions who had established provision through the Programme. **Mackenzie et al. (2016)** extends this work further by reporting on three interviews that were undertaken as part of a larger study (described in full in Tolley & Mackenzie, 2015; a summary of its key findings and implications for institutions is available in **Croft, Grove & Lawson (2016)**) to explore the views of university senior management (typically Pro-Vice Chancellors) towards mathematics and statistics support. The findings from the 23 semi-structured interviews highlighted the wide-ranging nature of the challenges faced by institutions in relation to mathematics and statistics, with all reporting having students who were experiencing difficulties with their mathematical and statistical learning. These challenges were not only experienced by undergraduate students, but also postgraduate students. Significantly, the work highlighted that senior management recognised "*that unless they provide appropriate forms of learning support for mathematics and statistics, it is inevitable that there will be an adverse impact on their students' satisfaction, retention, achievement and employability*" and as a consequence "*had identified issues and initiated some form of response*" (Tolley & Mackenzie, 2015;p.2).

For the first time there existed documented evidence that senior management within institutions were not only recognising the important role for mathematics support in addressing the mathematical challenges and difficulties faced by their learners, but were also overseeing institutional investment in appropriate provision. As **Mackenzie et al. (2016;p.558)** highlight "*it appears that each of the cases is already taking an ecological approach towards the management of its mathematics and statistics support and in so* *doing is adapting to, and evolving within its own ecological 'niche'"*, that is the institutional response was typically a tailored one to meet its individual needs and priorities. To help advise university senior management on the implementation and oversight of their mathematics support provision a dedicated guide was produced and distributed to institutions (**Croft, Grove & Lawson, 2016**).

Almost since its inception, the traditional model of delivering mathematics support within higher education has been through drop-in based provision with the personalised nature it affords known to be particularly valued by learners (Lawson et al., 2003). The diversification of institutional responses to the 'mathematics problem', typically tailored in nature to local circumstances, created the need to explore exactly how mathematics support was delivered and managed within institutions including the roles and recognition of those providing the support. In early 2016 a survey, targeted at staff responsible for the day-to-day operation of the mathematics support provision within their institutions, was launched by the author and his collaborators. The survey was structured so that the sustainability of mathematics support, from the perspective of those involved in its delivery, could also be analysed using the framework of **Grove & Pugh (2017)**. Findings from the survey are considered within two linked papers: **Grove, Croft, Lawson & Petrie (2018)** considers, from the perspective of the institution, the infrastructure associated with mathematics support, such as where it is located within institutions and how it is managed; and **Grove, Croft, Lawson & Petrie (2019)** explores, from the perspective of the staff involved in delivery, the role and recognition of those individuals providing mathematics support to learners.

The findings from this work demonstrate that not only do mathematics support centres within many institutions have access to their own dedicated facilities, but also, in a growing number of institutions they are now embedded as part of wider institutional student-focused provision, for example a library or an academic skills centre. On the whole, responsibility for the management of mathematics support rests outside of academic departments, yet there was evidence within half of the responding institutions of clear mechanisms being in place for feeding findings from mathematics and statistics support into mainstream teaching and learning and curriculum development. From the perspective of those delivering the support, the results show that the majority of staff with responsibility for the oversight of mathematics support within institutions are in permanent roles, and in a number of cases working in mathematics support is the sole focus of their employment. Further, there also exists evidence that staff feel recognised by their institutions and supported in pursuing opportunities to develop their roles, engage in professional development opportunities, and contribute to a growing national community of practice in mathematics support.

The survey offered new insight into the management and operation of mathematics support, and in particular provides validation of the earlier findings of Tolley & Mackenzie (2015) and **Mackenzie et al. (2016)**. The results from the survey show that investments are being made by institutions in their mathematics support provision through its alignment with the wider institutional infrastructure, the creation of dedicated staffing roles, and significantly in some institutions that mathematics support is no longer operating in isolation from mainstream teaching and learning. Such findings are clearly some way from the earlier reflections of Kyle (2010;p.103) who once commented "*Although I might not have put it in these terms at the time, I probably regarded mathematics support as a form of cottage industry practised by a few well meaning, possibly eccentric, individuals, who may themselves have been hard pushed to offer a credible rationale for this work…*".

Evidence for the tailoring of mathematics support provision by institutions first identified by **Mackenzie et al. (2016)** has also been found by **Grove et al. (2018;p.179)** who note the "*emergence of, or at the very least an exploration of new ways of, delivering mathematics and statistics support*" by institutions. This is further probed in the recent work of **Grove, Croft & Lawson (2019;p.1)** who have identified that there is now "*considerable variation in how this support is delivered within institutions. Whilst the drop-in model remains most common, we see evidence that the methods used to provide mathematics support are expanding*." Examples include not only the use of new technologies, but also the increased availability of mathematics support delivered via organised lectures or workshops or "*where mathematics support provision is now embedded within mainstream teaching*" **Grove, Croft & Lawson (2019;p.7)**. This finding is particularly significant as while these forms of support have the potential to reach a wider range of students, since students do not necessarily need to 'opt-in' to access them, their nature is such that they challenge the definition of mathematics support of being "*in addition* [my emphasis] *to their regular programme of teaching…*" (Lawson et al., 2003;p.9) and it is unlikely they are able to deliver some of the well documented benefits of traditional mathematics support (Solomon, Croft & Lawson, 2010). The recent review of the mathematics support research literature by **Lawson, Grove & Croft (2019;p.22)** to show its evolution identifies *"there is a growing body of literature identifying the impact of alternative approaches to mathematics support that extend beyond use of the drop-in model alone"*. However, they cite a note of caution as while individual studies do indicate value in these approaches, these studies are generally much smaller in nature than the "*large-scale studies of 'traditional' mathematics support* [that] *have provided strong evidence of its effectiveness*" **Lawson, Grove & Croft (2019;p.24).**

An important feature of the work described in **Grove et al. (2018;p.189)** is that it considers the sustainability of mathematics support within the context of the institutional support and commitment shown to it and they conclude that "*the evidence indicates that mathematics support appears a sustainable part of the teaching and learning provision within UK institutions*". **Grove, Croft, Lawson & Petrie (2019;p.57)** consider another dimension of sustainability through the practices of the individuals involved in its delivery and identify how "*staff working in mathematics support have been particularly active at adding a scholarship dimension to their roles*" and as such are developing careers within mathematics support and contributing to "*an increasing number of academic works relating to mathematics and statistics support being published*". The findings of **Grove, Croft & Lawson (2019;p.17)** in relation to the sustainability of mathematics support are even more unequivocal noting how mathematics support is becoming increasingly embedded within institutions and how it has now become a "*widely available, accessible and extensively used service within institutions to support students with the challenges that they may face with the mathematical components of their higher education studies*".

## 7. The Impact of Mathematics Support Upon Individuals

*7.1. Users of mathematics support*

There has long been a culture amongst those running mathematics support within institutions of collecting data to explore who uses the provision (see for example Croft (2000)). Whilst, as we have seen, there exists a growing body of literature reporting on its effectiveness in enhancing the student experience, until recently, the national scale of its usage by learners within higher education remained unknown. **Grove, Croft & Lawson (2019**), as part of their exploration of the extent and uptake of mathematics support across England and Wales, not only show that around 40% of responding institutions each supported over 1,000 student engagements with mathematics support in a typical academic year, but across England and Wales, were able to demonstrate in a typical academic year around 85,000 such engagements are made with mathematics support in the 68 institutions who returned data. Whilst, as they note, any figures should be interpreted with a degree of caution, this clear and extensive use by learners presents "*perhaps the most compelling evidence of mathematics support becoming embedded within institutions*" **Grove, Croft & Lawson (2019;p.15**).

A further aspect of their work is that it explores the groups that were able to access mathematics support within institutions. In one sense the results are not surprising as within all responding institutions the support is available to undergraduate students, albeit with some restrictions in around 20% of cases. A significant finding is that in the majority of institutions (75% and 60% respectively) it is also available for use by postgraduate taught (for example those studying master's degrees) and postgraduate research students. Its wide availability to postgraduate students is evidence of a response to one of the issues identified from the interviews with university senior management by **Mackenzie et al. (2016)** who articulated their concerns in relation to the skills of some of their postgraduates, particularly in relation to quantitative research methods. In just over 30% of institutions, mathematics support is also available to staff members including those with teaching responsibilities. Furthermore, in just under 10% of cases there existed evidence of it being "*tailored by institutions to meet their specific needs and circumstances*", that is being made available to other groups of learners beyond its initial mission and remit, for example students within partner organisations and alumni (**Grove, Croft & Lawson, 2019;p.9)**.

*7.2. The specialist and more-able mathematics student*

It is interesting to note that **Grove, Croft & Lawson (2019)** identify that mathematics support is not universally available to all undergraduate students. Whilst full details of these restrictions were typically not provided by respondents as part of their work, **Grove, Croft, Lawson & Petrie (2019)** identify that some institutions restrict access to mathematics support by specialist, that is single honours, mathematics students. They do, however, also note several instances, in large research-intensive institutions, whereby students from the later years of mathematics degrees are attending and support is offered, even though this is not necessarily the primary mission of the centres. This finding led **Grove, Croft, Lawson & Petrie (2019;p.48)** to conclude that the availability and usage by specialist mathematics students in their later-years "*highlights a broadening of the role of mathematics support*" and a shift from its origins of being "*established to support those students in the disciplines of mathematics, engineering and physics with their learning of mathematics as they made the transition* [my emphasis] *to university study*".

The use of and access to mathematics support by specialist students are issues that have been considered by the author for some time. For example **Croft & Grove (2006;p.1)** discuss evidence of "*problems emerging in later years, particularly year 2 of single honours mathematics programmes, with disillusionment amongst parts of the cohort and high drop-out rates*" and makes suggestions as to how this might be tackled, including a role for mathematics support. In their later discussion of this so-called 'sophomore slump', **Croft & Grove (2015)** synthesise the nature of the challenges experienced by specialist mathematics students in the later-years of their studies into five main themes, and provide a comprehensive discussion of the evidence for each as drawn from the published research literature. The themes they highlight include: The importance of inclusion within an academic community; the quality of university teaching; a lack of alignment between the pedagogic practices of mathematical sciences departments and the preferred learning styles of students; changing perceptions of academic success and motivation; and, the apparent lack of relevance and application of the topics being studied. Significantly, this work goes on to highlight a number of possible interventions, several of which emerged from activities undertaken as part of the National HE STEM Programme (**Grove, 2013b**), that "*provide pointers to possible ways forward*" **Croft & Grove (2015;p.181).**

Of the possible approaches **Croft & Grove (2015)** highlight for tackling these documented issues, three themes align with features of mathematics support known to be valued by learners: suitable study spaces for use by students; peer-support, and staff-student communities. Whilst students are known to use mathematics support for the individual interaction that it affords with a skilled and knowledgeable tutor who "*who is willing to take time to explain things to them*" (Lawson et al., 2002;p.26), there is also evidence that they use mathematics support facilities to engage in more social forms of learning (Solomon, Croft & Lawson, 2010). **Croft, Grove & Bright (2008;p.12)** describe the piloting of an activity and resource centre for specialist mathematics students in the later years of their studies that was established because the existing mathematics support centre "*had become so busy that use was restricted to first year mathematicians so removing entirely any learning space for those in year 2 and beyond.*" This activity and resource centre differed from a 'traditional' mathematics support centre in that it was not staffed by tutors providing mathematical advice and guidance, although staff offices were located nearby, it instead formed a readily accessible learning space in which students could work freely with access to a range of resources, for example computers and books. Evidence obtained from those students who used the new learning space indicated they were using it for social learning and that "*many students attend the* *centre in groups to work informally on coursework problems*" and "*peer support within these groups is often clearly evident*" **Croft, Grove & Bright (2008;p.15)**.

One of the most comprehensive studies of the engagement of specialist mathematics students with mathematics support has recently been undertaken by the author (**Grove, Guiry & Croft, 2019)**. In studying the historical usage data of a mathematics support centre within a large research-intensive university, the extent to which it was being used by specialist mathematics students became increasingly apparent. These were not students in year 1 of their studies: "*The proportion of visits made by specialist mathematics year 1 students has declined over time from just under two-thirds in 2012/2013 to just over 20% in 2017/2018; over the same period, the proportion of total visits made by specialist mathematics students in years 2 and 3 combined has increased from just under a third to around 70% (with a peak of almost 80% in 2016/2017)" (***Grove, Guiry & Croft, 2019;p.8)**. Significantly, they were also not 'failing' students, nor were they students who had used the centre regularly since commencing their undergraduate studies, these were users who were choosing "*to do so as, and when, a specific need arises"* (**Grove, Guiry & Croft, 2019;p.9)**. While **Grove, Croft, Lawson & Petrie (2019)** find some institutions restrict access to mathematics support by specialist mathematics learners, this work demonstrates where such students are able to access the provision, "*they do so in large numbers*" **Grove, Croft & Lawson (2019)**.

The work of **Grove, Guiry & Croft (2019)** not only explores the reasons why this cohort chose to access mathematics support so extensively, but also their use of the additional learning opportunities and resources made available as part of their undergraduate studies. Their findings indicate that while the students generally demonstrated high levels of engagement with the core components of their studies, for example lectures, the "*additional, and optional, opportunities for personalized support and dialogue provided by the mathematics department to support their studies are less well used and valued*" (**Grove, Guiry & Croft, 2019;p.1)**. One of the reasons cited for this lack of use by students is the fact that these opportunities do not always align with their preferred learning style, something **Grove & Croft (2015)** have noted previously. Instead, students are turning to their friends and the mathematics support centre when they require additional support or guidance. Indeed, a key finding drawn from this work is the value that mathematics students place on engaging in dialogue about their mathematical learning. This is something that has been noted in the context of mathematics support by Solomon, Croft & Lawson (2010), and more broadly by Williams (2015), although in this latter case it involved mathematics students making the transition to university rather than those in the later years of their studies.

An important question in the research of **Grove, Guiry & Croft (2019)** is why the students in their study were turning to the mathematics support centre over other forms of support. One of the key findings relates to the fact that the postgraduate students working as tutors within the centre are all drawn from the School of Mathematics. In some instances the students consider visiting the centre to speak with a tutor as an extension of peer support and appear "*to consider the tutors as their mathematically more experienced peers*" (**Grove, Guiry & Croft, 2019;p.23)**. A related study by **Grove & Good (2019)**, considering students from the same mathematics department, offers further insight into their use of mathematics support. Although this study focuses upon their views and experiences of the feedback that they receive as part of their undergraduate studies, it shows the "*feedback perceived as most valuable involves opportunities to engage in dialogue about their work with either their peers, postgraduate teaching assistants, or academic members of staff*" (**Grove & Good, 2019;p.1)**. As such, it reinforces the value that mathematics students place on opportunities to engage in dialogue about their learning with others, and engaging with mathematics support affords a convenient opportunity for them to do so. Indeed, within the wider literature, studies have indicated that students are particularly receptive to advice received during one-to-one feedback dialogue sessions (Duncan, 2007) and view these as 'safe spaces' within which they can engage in dialogue about their own work and learning (Cramp, 2011).

*7.3. Tutors within mathematics support*

The extensive use of mathematics support by specialist mathematics students poses particular challenges for those who tutor within such centres, not just in terms of the level or specialism of the subject knowledge required, but also in terms of the pedagogies associated with providing support to such advanced learners. The recent work of **Grove, Croft & Lawson (2019)** demonstrates that across the UK and Ireland, while around 80% of centres have dedicated full or part-time staff working within mathematics support, in almost 50% of institutions, postgraduate students also have an important role working as tutors. Further, within six of the research-intensive (Russell

Group) institutions across England and Wales, postgraduates were the sole tutors within mathematics support.

There has been significant work over recent years to provide support to the postgraduate student who works, and indeed anyone else new to doing so, within a mathematics support environment. In 2005, and as described in **Grove, Kyle & Cox (2006)** the author established a national training programme for postgraduate teaching assistants in the mathematical sciences. Building upon this, **Croft & Grove (2016)** describe in detail a model for training anyone new to working in mathematics support that has now been successfully implemented within the UK for many years.

Those new to tutoring in mathematics support now have access to a wide range of resources and training opportunities (**Croft & Grove, 2011**; Fitzmaurice et al., 2016), although as **Grove et al. (2018)** found, some 50% of institutions report not routinely offering training to those new to working within mathematics support. As previously noted (Section 5), **Grove, Croft, Lawson & Petrie (2019)** explores mathematics support from the perspective of the staff member. However, the day-to-day realities of working within a mathematics support centre, and the interactions that take place with learners, had not previously received consideration. This shortcoming has been rectified by the author in **Grove & Croft (2019)**.

**Grove & Croft (2019)** presents the results from a research study exploring the role, experiences and aspirations of a community of mathematics postgraduates as they learn to become tutors within a mathematics support centre. Analysed through the lens of communities of practice (Lave & Wenger, 1991) it offers insight on their personal trajectories as 'newcomers' to the peculiarities of tutoring within a mathematics support centre, a task which is very different from the more mainstream task of supporting teaching and learning activities within academic departments (**Grove, Mac an Bhaird & O'Sullivan, 2019**). In particular the work of **Grove & Croft (2019)** highlights the way in which this group of tutors, who form part of a strong postgraduate community, learn from, support and cooperate with each other in their common endeavour of supporting the mathematical learning of students. It demonstrates how they develop their skills and confidence as tutors, how they contribute to the work of the centre, for example in helping to recruit new tutors, and how working in the centre will inform their own future careers as academics.

As **Grove & Croft (2019;p.257)** note "*because the nature of tutoring in a support centre is quite different from other aspects of the postgraduates' work, they must learn* [their emphasis] *to become tutors and then learn* [again their emphasis] *to become better tutors. By and large, this learning is situated 'on the job…'*". Whilst tutors may initially draw upon their own prior experience, including from any initial training they may have been given they "*soon learn that this is insufficient*" and have to develop new strategies for coping with the demands and challenges of working in a mathematics support centre. In developing these new strategies **Grove & Croft (2019;p.258)** go on to note how, amongst a community of around 20 tutors, "*belonging to a large and diverse community of mathematics support tutors was a distinct advantage which helped in* *numerous ways*", and as such there is great value in being part of a mathematics support community where expertise can be shared and learning gained from each other. In the case of this institution, there were sufficient numbers of tutors working in mathematics support for such a community to develop. However, **Grove, Croft & Lawson (2019**) found that in around 10% of institutions who reported they had specific full-time or part-time staff employed to deliver mathematics support it was a single member of staff delivering the entire support provision; for some, working in mathematics support can be an isolated endeavour. As such there is great value in the national mathematics support community described by **Croft et al. (2015)**.

The findings of **Grove & Croft (2019)** have wider implications for the training of those working in mathematics support as they highlight that a single training session is insufficient. They argue that it should be complemented "*by an on-going set of regular continuing professional development opportunities in recognition of the fact that most learning is situated in practice*" **(Grove & Croft, 2019;p.261)**, and include opportunities for tutors to reflect upon their skills, share practices, learn from those who are more experienced, and benefit from, or access, the particular skills of other tutors. In addition to **Grove, Mac an Bhaird & O'Sullivan (2019)** providing a summary of the development of training provision for postgraduate students involved in mathematics support across the UK and Ireland, they also describe how they are now evolving, using the findings from practice and research, the current training provision across the UK and Ireland to form a structured and accredited series of developmental opportunities so that postgraduates can receive formal recognition for their teaching endeavours.

*7.4. Influencing mainstream teaching and learning practices*

The final approach identified by **Croft & Grove (2015)** to tackling the observed 'sophomore slump' amongst specialist mathematics students is one of context-based and problem-based learning, that is where the learning of a topic is firmly grounded within practical or real-world applications. This model of delivery proposes a direct response to the issues identified by Brown (2005;p.4) who reported "*many of these same* [disillusioned] *students reported their disappointment that the mathematics they were now learning had become so pure as to have no possible application*". However **Grove (2012;p.16)** proposes that the 'mathematics problem' as now observed is in fact a multi-stage one where the "*dominant issue* [amongst mathematics students] *appears to be an inability to apply mathematics rather than an inability to undertake the 'routine processing' of calculations; in particular, students struggle to identify the techniques and approaches required to solve problems*". As such, introducing a context-based or problem-based learning approach without appropriate scaffolding is unlikely to be effective and risks creating further disillusionment amongst a cohort.

**Savage & Grove (2015)** report on a successful, and evaluated, intervention which was designed to help scaffold students develop essential skills in mathematical modelling and problem solving as part of a year 1 mechanics module. Rather than being taught through traditional lectures, new mathematical ideas were introduced to students by them first tackling increasingly sophisticated, and importantly unfamiliar, problems within teams; as such, it formed a genuine model of context-based and problem-based learning (Belt & Overton, 2007). A feature of this work was its subsequent adaptation to create two modules, delivered via workshops rather than lectures, within year 1 and year 2, of a mathematics degree. Whilst these modules are only briefly described within **Grove & Good (2019;p.7)** their key feature is that they foster "*extensive peer-peer dialogue*" and allow students to access "*a large amount of personalised support…from the module lecturer…and from postgraduate teaching assistants acting as advisors to a small number of groups with whom they worked closely throughout the formal sessions*". Significantly, as **Grove & Good (2019)** find, these were the modules where students reported they were most satisfied with the feedback received on their learning through the natural opportunities for dialogue that they created. Whilst only one instance, this approach forms an example of how using the findings from mathematics support, in this case the value that students place upon meaningful mathematical dialogue with others, can influence mainstream teaching and learning (**Grove et al. 2018)**.

## 8. Conclusion

The work described here is concerned with the author's interest and research into how UK universities' provision of mathematics support has grown over the last 25 years in response to ill-preparedness of students upon arrival at university and insufficient numbers of mathematically-well-qualified students wanting to study STEM disciplines. Papers cited explicitly illustrate the contribution of the author to both the knowledge base in this field and its impact on policy and practice within higher education institutions. New UK-wide surveys conducted as part of this body of work, and detailed specifically within Section 6 quantify this growth, and provide important evidence of the extensive, and diverse, range of users who now choose to access mathematics support within higher education institutions. Through programmes of activity involving large numbers of universities across England and Wales, the author has been instrumental in the drive to encourage many more students to study STEM subjects and mathematics in particular. The ways this has been achieved are described within the publications referred to in Section 4 and his later work demonstrates the important role of mathematics support in assisting learners, from across the STEM disciplines, in addressing the mathematical challenges and difficulties that they may encounter during their studies.

Throughout this period mathematics support has evolved within the UK in several ways. Through the research works described in Section 7, the author has been able to chart developments in terms of who provides this support within institutions, the challenges that they face, and its impacts upon their personal and professional aspirations and development. At the same time, the research detailed in Section 6 shows how the oversight of mathematics support within universities has shifted so that activity is frequently now a part of mainstream institutional student support, and its importance to enhancing the overall student learning experience is increasingly recognised by university senior management. Significantly the research demonstrates how the delivery of mathematics support is now diversifying within institutions, and how its delivery is being increasingly 'tailored' by institutions to meet their specific needs and circumstances. The long-standing interest of the author in measuring the sustainability of higher education initiatives has been used to explore the sustainability of mathematics support provision from both the perspective of the institution and those who deliver it, and demonstrates that mathematics support is not only an important part of institutional provision and practice, but is increasingly becoming a career pathway for many individuals as a result of the increasing range of staffing appointments that are now being made in this area.

Finally, the work undertaken here, and described within Section 7, shows an important milestone in the evolution of mathematics support. It demonstrates not only its acceptance by learners through their large-scale usage of it, but significantly that mathematics support is not a service accessed only by the struggling student; it is now one that is increasingly valued by the specialist and more-able mathematics student as a means of further consolidating and enhancing their mathematical learning. Significantly work undertaken to explore delivery of aspects of the mathematics curriculum show how the pedagogic practices of academic departments most valued by students align with several key features of mathematics support. Through the incorporation of practices derived from mathematics support, positive enhancements can be made to the student learning experience for all students by departments.

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**sigma**
Lanchester Library
Much Park Street
Coventry University
Coventry CV1 2HF

1 November 2019

To whom it may concern,

## Re: Michael Grove – Application for PhD by Published Work

We have been research collaborators with Michael Grove for well over a decade. We both first co-authored a paper with Michael (different papers) in 2006. One or both of us are co-authors on 13 of the 26 publications in Michael's list of *Works Submitted for Consideration.* It is fair to say that we have been his principal collaborators over this period.

In terms of the work that we have produced together, we find it impossible to go through on a paper by paper basis and assign a percentage to measure the input of each of us to that particular output. Our approach has always been that we have been three equal contributors to the work in hand – equal in the sense of the input of ideas, the value given to those ideas and the ownership of the final output. In some instances, one of us has taken the lead on actually producing the first draft of a manuscript with the other two then commenting and amending as appropriate. In other instances, we have divided the work to be reported amongst us and then communally edited the resulting assembly.

We would emphasise most strongly that the relationship was never one of master and apprentice but always one of partnership where each of us brought valued expertise to the collaboration and the quality of the research was dependent on all three of us. In this sense, we would not identify a "lead contributor" for any research paper but rather state that each of us has full ownership of the findings of each paper – the work would not have been the same without the input of any one of us.

We have read Michael's commentary on his work and are convinced that what he has presented is a fair representation of ***his*** work and that he is not seeking to take credit for our work or the work of others. We also believe that he has made an overwhelming case for being awarded a PhD by Published Work. The volume and importance of his work in mathematics support is enormous. He has made a huge contribution to shaping the field over the last decade.

Yours faithfully

[redacted]

[redacted]

Professor Tony Croft
Mathematics Education Centre
Loughborough University
a.c.croft@lboro.ac.uk

Professor Duncan Lawson MBE
**Sigma**
Coventry University
duncan.lawson@coventry.ac.uk

UNIVERSITY OF BIRMINGHAM

School of Mathematics
Birmingham
B15 2TT
UK
+44 (0)121 414 6201
+44 (0)121 414 6594
c.good@bham.ac.uk

12/11/2019

To whom it may concern

**Statement of Authorship for papers co-authored with Michael Grove of the University of Birmingham**

I was a co-author with Michael Grove on one of the papers that is being considered for the award of PhD by publication.

The paper in question is:

Grove, M.J. & Good, C. (2019). 'Approaches to feedback in the mathematical sciences: just what do students really think?' to appear in *Teaching Mathematics and its Applications*. (https://doi.org/10.1093/teamat/hrz013)

This paper grew out of conversations that Michael and I had about improving feedback provided for continuous assessment in the School of Mathematics. My contribution to the paper was limited to designing some of the initial approaches to feedback and working out the logistics of implementing them with Michael. Michael was responsible for collecting the data, analysing the results and writing the paper. My contribution to this paper was certainly no more than 30%.

If you require further information about this publication, please do not hesitate to contact me.

Yours sincerely

[redacted]

Chris Good
Professor of Mathematics
Deputy Head of School

To whom it may concern

Statement of Authorship for paper co-authored with Michael Grove of the University of Birmingham

I was a co-author with Michael Grove on one of the papers that are being considered for the award of PhD by publication.

In this letter, I set out the division of labour for the following paper:

**Grove, M.J.** & Kyle, J. (2014). Enquiry into Learning and Teaching in Mathematics and Engineering. In Cleaver, E., Lintern, M., McLinden, M. (Eds.), Teaching and Learning in Higher Education: Disciplinary Approaches to Educational Enquiry (pp.126-145). London, UK: SAGE.

Michael deserves the overwhelming credit for this paper. From the initial concept through the final draft, it was Michael who took the lead and undertook the vast majority of the work. I played a part in scoping discussions at an early stage and then, at a later stage, by offering editorial suggestions on an early draft. Were I to estimate our respective contributions to this paper, this would be 95% from Michael, 5% from me.

I hope that this letter has provided sufficient information. Please do not hesitate to contact me if you require any further input.

Yours faithfully,

[redacted]

Dr J Kyle,
Formerly, School of Mathematics,
University of Birmingham.

21 October 2019.

Maynooth University
National University of Ireland Maynooth

Maynooth University Department of Mathematics and Statistics
Roinn na Matamaitice agus na Staitistice Ollscoil Mhá Nuad

4th December 2019

To whom it may concern

**Re: Michael Grove submission for PhD by Published Work**

We are writing with regard to the following published work that we recently jointly authored with Michael:

Grove, M.J., Mac an Bhaird, C. & O'Sullivan, C. (2019). Professional development opportunities for tutors of mathematics learning support. *MSOR Connections*, 18(1), pp. 4-15.

We have long been aware of Michael's work in the UK to support those who are new to teaching mathematics within UK higher education, and as a mathematics support community within Ireland, we have utilised several of his previous publications in the development of training materials for our own postgraduate students working in a mathematics support environment. Following Michael's presentation at the 2016 Irish Mathematics Learning Support (IMLSN) Network conference we began a collaborative initiative with a view to offering an accredited model of training for postgraduate students within Ireland. It was through our mutual enthusiasm, willingness to collaborate, and sharing of ideas that we were able to develop the model of training. These new developments formed a collective endeavour and Michael took a leading role in the development and writing of the paper (Grove et al., 2019) which provides an essential overview and historical context to our recent collaboration on this model. In particular, the case study focused upon the UK is based entirely upon his current and historical activities in this area. The training model was piloted in 2018-19 and this is currently being written up in a follow-on research paper with Michael.

It has been a pleasure to collaborate with Michael, and we very much look forward to continuing to do so as this initiative develops further in the future.

Your faithfully,

[redacted]

Ciaran O'Sullivan,

Technological University Dublin

[redacted]

Ciarán Mac an Bhaird

Maynooth University

Maynooth University Department of Mathematics and Statistics, Maynooth, Co. Kildare, Ireland.
Roinn na Matamaitice agus na Staitistice Ollscoil Mhá Nuad, Maigh Nuad, Co. Chill Dara, Éire.

**Tel/Teil:** +353 1 708 3914 **Fax/Facs:** +353 1 708 3913 **Email/Ríomhphost:** support@maths.nuim.ie
https://www.maynoothuniversity.ie/mathematics-and-statistics

To whom it may concern

**Re: Michael Grove submission for PhD by Published Work**

I am writing with regard to the following two published works that I jointly authored with Michael:

McLinden, M.T., Grove, M.J., Green, J.R. & Birch, A. (2019). Developing and embedding inclusive policy and practice within higher education institutions. In Krčmář, K. (Ed.), *The Inclusivity Gap* (pp. 160–176). Aberdeen, UK: Inspired By Learning.

McLinden, M.T., Grove, M.J., Green, J.R. & Birch, A. (2014). Developing and embedding inclusive policy and practice within the University of Birmingham. *Education in Practice*, 1(1), pp. 18-21.

For over five years we have discussed, explored and debated how to evidence progress towards genuine practice change within higher education and these two works demonstrate the results of our joint academic endeavour to develop an appropriate framework. This work formed a partnership that was equal in the development and application of ideas and in the production of the published works noted above. Working collaboratively, along with other colleagues, we were able to pilot the framework within the University and then disseminate it more widely. Whilst this formed a partnership activity, the work, and the resulting two publications described here would not have been possible without the ideas, vision, hard work and enthusiasm shown by Michael – it was a pleasure, and indeed it continues to be, to work with him.

Your faithfully,

[redacted]

Professor Mike McLinden,
School of Education, University of Birmingham

UNIVERSITY OF LEEDS

School of Physics and Astronomy

University of Leeds

Leeds LS2 9JT

16th September 2019

To whom it may concern:

**Statement of Authorship for papers co-authored with Michael Grove of the University of Birmingham**

I was a co-author with Michael Grove on two of the papers that are being considered for the award of PhD by publication. I would like to explain the division of labour for each paper.

**Grove, M.J.** & Pugh, S.L. (2015) Is a conceptual understanding of maths vital for chemistry? *Education in Chemistry*, 52(1), pp. 26-29.

Michael was first author for this paper. Whilst it was the outcome of a collaborative project, Michael took a lead in designing the research paper and for the mathematics elements of the paper. I provided input on the chemistry aspects of the paper. The actual writing of the paper was a joint endeavour. If I were to assign a weighting to the efforts of the authors, I would assign this paper as 60:40 in Michael's favour.

**Grove, M. J.** & Pugh, S. L. (2017). Defining 'sustainability indicators' for higher education teaching and learning innovations. *Education in Practice*, 3, pp. 13–18.

Michael was the driving force behind this paper. He wrote the majority of the paper. My role was in discussing his initial ideas, and then providing editorial input once he had written the paper. If I were to assign a weighting to this paper, I would assign 90:10 in Michael's favour.

I hope that this letter has provided sufficient information. Please do not hesitate to contact me if you require any further input.

Yours faithfully

[redacted]

Dr Samantha Pugh

Associate Professor in STEM Education

School of Physics & Astronomy
University of Leeds
Leeds LS2 9JT
England

13th September 2019

Dear Michael,

I am writing with regard to your proposed submission of a PhD by Published Work at the University of Birmingham and specifically, to the following book chapter, that we jointly authored:

Savage, M.D. & Grove, M.J. (2015). Mathematical Modelling and Problem Solving: High-level skills for higher education STEM students. In Grove, M.J., Croft, A.C., Kyle, J. and Lawson, D.A. (Eds.) *Transitions in Undergraduate Mathematics Education* (pp.). Birmingham, UK: University of Birmingham and Higher Education Academy.

The work, described in this chapter, relates to a large-scale project that was established with the support of the National HE STEM Programme, of which you were the Director at the time. In addition to the financial resource provided by the Programme, I was pleased to be able to work with you, on the design and delivery of the activities described-including the teaching sessions within the School of Physics and Astronomy at the University of Leeds. Working together, we were able to pilot and evaluate this programme and, through the research work undertaken, also able to roll the programme out to a further 12 departments through the initiatives that you had established.

I am now very pleased indeed that we have this published chapter - as a record of our collaborative activities.

With Best Wishes,

[redacted]

Professor Mike Savage,
Emeritus Professor, University of Leeds

# A1. The evolution of mathematics support: a literature review

Lawson, D.A., **Grove, M.J.** & Croft, A.C. (2019). The evolution of mathematics support: a literature review. I*nternational Journal of Mathematical Education in Science and Technology*. Advance online publication

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# The evolution of mathematics support: a literature review

**By Duncan Lawson, Michael Grove and Tony Croft**

Duncan Lawson, **sigma**, Coventry University, Coventry, CV1 5FB.
ORCiD: 0000-0002-6829-1444

Michael Grove, School of Mathematics, University of Birmingham, Birmingham, B15 2TT.
ORCiD: 0000-0002-3150-125X

Tony Croft, Mathematics Education Centre, Loughborough University, Loughborough, LE11 3TU.
ORCiD: 0000-0002-7980-9579

Corresponding author: Duncan Lawson, duncan.lawson@coventry.ac.uk

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# The evolution of mathematics support: a literature review


## Abstract

Mathematics support, the provision of additional learning opportunities to, primarily, non-mathematics specialist undergraduates has grown significantly since the early 1990s, particularly in the UK, Ireland and Australia. Alongside the growth in volume of provision, there has been a marked increase in the amount of research and scholarship relating to mathematics support that has been carried out and disseminated. This paper reviews this literature and in doing so identifies areas in which mathematics support has evolved. This evolution has taken place in response to a range of crucial changes in the external policy and general environment and, in particular, in response to the changing nature of the so-called 'Mathematics Problem'. Key themes that emerge from the literature review, which are explored in detail, are the characteristics of students who engage with mathematics support and reasons why others do not; the role of the mathematics support tutor, who undertakes the tutoring task and how they are trained; the positioning of mathematics support within higher education structures; and the evaluation of the effectiveness of mathematics support.


**Keywords:** mathematics support, literature review, impact, evaluation.

## 1. Introduction

Mathematics support has been defined as 'a facility offered to students (not necessarily of mathematics) which is in addition to their regular programmes of teaching through lectures, tutorials, seminars, problems classes, personal tutorials, etc.' [1,p.9]. The two dominant forms of mathematics support are the drop-in centre and the bookable one-to-one appointment. Whilst the informal provision of extra support for students by committed mathematics lecturers has a very long history, what might be termed 'organised mathematics support' began in earnest in the UK less than thirty years ago in the early 1990s. The primary impetus for the development of mathematics support provision was what has become known as the 'Mathematics Problem'. This is discussed in more detail in the following section; for the present, the 'Mathematics Problem' can be summarised as the under-preparedness of new undergraduates (primarily in non-mathematical sciences disciplines) for the mathematical and/or statistical demands of their degree programme. *Making Mathematics Count* [2], the report of a Government Inquiry into post-14 mathematics education in Britain, includes the oft-quoted statement:

> In the short-term, the Inquiry believes that Higher Education has little option but to accommodate to the students emerging from the current GCE process[1]. [2, p.95]

[1] The GCE process refers to the qualifications taken by most students at that time immediately before entry to university, primarily Advanced levels also known as A-levels.

The provision of mathematics support was the response that many institutions had already put into place to make the required 'accommodation', in some institutions over a decade before the Smith Inquiry reached the above conclusion.

Mathematics support began as a response to circumstances that pertained in the late 1980s and early 1990s. A key motivation for the introduction of mathematics support was to attempt to tackle the problem of high failure rates on engineering degree courses. The engineering mathematics modules were seen as one of the major causes of these high failure rates [3]. Given that engineering courses typically recruited large numbers of students, high failure rates on these courses represented a major setback for many individual students and a significant loss of income to institutions. Mathematics support as originally established was therefore primarily remedial and often targeted at engineering students and, to a lesser extent, physical sciences students.

Over the last thirty years, the environment in which higher education in the UK operates has changed enormously and mathematics support provision has evolved in response to these changes. Key changes in both the policy and general external environment include:

- The election of the 1997 Labour Government whose leader, Tony Blair, set a target of 50% of young adults going into higher education in the next century [4]. To achieve this target, emphasis was placed on Widening Participation in Higher Education, as set out in the green paper *The Learning Age*: 'We cannot rely on a small elite, no matter how highly educated or how highly paid. Instead we need the creativity, enterprise and scholarship of all our people' [5,p.7]. The increased focus on widening participation resulted in student cohorts with even greater inhomogeneity in their mathematical backgrounds and created new challenges for mathematics support.
- The introduction of university tuition fees in 1998 at the level of £1,000 per year and the subsequent 200% increases to £3,000 per year in 2006 and £9,000 per year in 2012. This created the notion of 'students as consumers' [6] and with it demands from students for increasing levels of support to ensure their success.
- Alongside the introduction of fees has been the general marketisation of higher education and competition between higher education providers has grown significantly. Competition for students has led universities to place more emphasis on their support services as a way of attracting potential recruits.
- A greater focus on student employment. The Destinations of Leavers from Higher Education (DLHE) survey was introduced in 2003 and its importance has grown since then. In 2017/18, the Teaching Excellence Framework relied on six core metrics (three of which were fully weighted and three of which were half weighted); of these, two of the fully weighted metrics were derived from the DLHE [7].
- Graduate employers have placed greater emphasis on applicants' quantitative skills and numerical reasoning tests are now routinely used as part of the selection process for a great many graduate jobs [8]. This has been challenging for many students, particularly those studying non-quantitative disciplines, and has created new demand for a different kind of mathematics support.

- The increasing quantification of many disciplines. In the early 1990s, the users of mathematics support were mainly students of engineering and the physical sciences. However, technological and scientific advances over the last 30 years have resulted in many subjects such as the biosciences and social sciences becoming much more reliant on mathematical modelling and statistical analysis (see, for example, [9,10]). These changes in the nature of practice in several disciplines have produced demand for support, particularly in statistics, from groups of students who previously would not have sought such support.

Mathematics support provision has responded to these and other changes in the higher education environment to establish itself as a permanent feature of the higher education landscape. Whilst once mathematics support may have been regarded as a 'Cinderella service' [11], according to Youdan [12,p.49] it is now viewed as an essential part of the provision of a university:

> Mathematics and statistics support has now attained a critical mass and overcome the significant hurdle where universities worry whether offering such support is an indication of modest aspirations. The accepted position is now that it is a student's right to receive support with the mathematical content of their degree.

This paper reflects on the evolution in the nature of mathematics support and the way that it is viewed through exploring a number of key themes. In the next section, the changing nature of the 'Mathematics Problem' is described in some detail. This is followed by sections addressing who the users of mathematics support are; who the tutors providing mathematics support are and how they are trained for this role; how mathematics support is positioned within the structures of higher education; and, evaluating the effectiveness of mathematics support.

Particularly in this century, those who deliver mathematics support have engaged in research and scholarship to underpin and develop their practice [13,14]. This has resulted in an ever-increasing literature base. The themes outlined in the previous paragraphs have been identified through a systematic review of the mathematics support literature dating back to 2000, covering the majority of English language mathematics education research journals as well as some broader higher education research journals. A range of the grey literature, particularly practitioner association and professional body publications, has also been examined; although, due to the nature of grey literature, this review has not been as systematic as the review of journal publications. In addition to this literature, there is a substantial body of conference publications, notably from the CETL-MSOR (Continuing Excellence in Teaching and Learning in Mathematics, Statistics and Operational Research) series of annual conferences. We have chosen to not systematically review conference presentations, since significant work in mathematics support that has been presented at conferences usually leads on to a journal or other publication. The few conference papers that are cited in this paper have no relevant follow-on publication. We have also drawn on some publications before 2000 where these have been cited in articles we have reviewed and/or where the publication provides important baseline information relating to the evolutionary development of mathematics support provision.

## 2. The Mathematics Problem

In the late 1980s, higher education institutions (HEIs) in the UK identified problems with high drop out and failure rates in mathematically based courses and low enrolment in courses with A-level mathematics entry requirements [15]. Several HEIs responded to this phenomenon by introducing some kind of mathematics support, such as drop-in workshops and bridging courses. Such responses were typically bespoke to the local situation and introduced by staff 'at the chalk-face' as an attempt to improve the outcomes for their students. Whilst most academic staff aware of these issues may have complained internally to their colleagues, a few decided to try to raise the profile of this issue nationally. In 1994, several articles appeared in the national press highlighting some of the issues under headlines such as '*Where x = inadequate teaching'* [16], '*Engineers unable to bridge the maths gap'* [17], '*Superior sums that don't add up to much'* [18].

The following year, two major reports were published by professional bodies and learned societies: *The changing mathematical background of undergraduate engineers* [19] and *Tackling the mathematics problem* [20]. These reports highlighted that new undergraduates, particularly those in the engineering and physical sciences disciplines, on entry to university, did not have the same range of mathematical skills as their counterparts from previous years. Sutherland and Pozzi [19], Commissioned by the Engineering Council, surveyed academic staff involved in teaching mathematics to engineering undergraduates. One of their most notable findings was that 83% of those surveyed "expressed considerable concern about students' facility with algebraic manipulation" [19,p.5]. The joint report [20] from the London Mathematical Society, the Institute of Mathematics and Its Applications and the Royal Statistical Society (the three leading learned and professional societies in the mathematical sciences in the UK), highlighted that:

> The serious problems perceived by those in higher education are:
> 1. A serious lack of essential technical facility – the ability to undertake numerical and algebraic calculation with fluency and accuracy;
> 2. A marked decline in analytical powers when faced with simple problems requiring more than one step;
> 3. A changed perception of what mathematics is – in particular of the essential place within it of precision and proof [20,p.2].

This report also introduced the phrase the 'Mathematics Problem' as a shorthand for the inadequate preparation of many new undergraduates for the mathematical demands of their course.

Both of these reports drew primarily on the opinions of academic staff. LMS et al. acknowledge that the analysis in their report 'is based on *judgement*, and is not susceptible of absolute "proof"' [20,p.2]. In 2000, the Engineering Council published a further report *Measuring the Mathematics Problem* [21]. This report sought to use quantitative evidence alongside the judgement of academic staff to highlight the mathematics problem. Significant quantitative evidence was provided by Lawson [22]. This analysis explored results from diagnostic testing of new students on entry to university. The same test had been used every year since 1991. The results showed year on year decline in performance of students with the same A-level mathematics grade and also showed that students entering university in 1997 with a grade C in A-level mathematics performed at the same level on the diagnostic test as students entering university in 1991 with a grade N[2] ('narrow fail'). Later work [23] showed that the 2001 A-level mathematics grade B cohort had remarkably similar performance to the 1991 grade N cohort.

Alongside the discourse that pre-university mathematics qualifications no longer adequately prepared new undergraduates for the mathematical demands of their courses, there was a second theme relating to the national policy of widening participation in higher education. According to Kent et al. [24,p.10], writing about the situation at Imperial College, London[3]:

> the expansion in student numbers means that departments which used to insist on a good A-level in maths, in addition to good grades in the 'core' topics, no longer do so. For example, last year in the Chemistry Department about 20% of students had A-level grade D or E or GCSE[4].

If an institution as prestigious as Imperial College had been forced to drop the entry requirement of a good grade in mathematics A-level for some of its engineering and science courses in order to recruit the required number of students then this would have become the practice across the sector. This problem was further exacerbated following the introduction of Curriculum 2000 (a reform of the entire A-level system) which a later Government inquiry bluntly stated was 'a disaster for mathematics' [2,p.8]. One manifestation of this 'disaster' was that the number of entries for A-level Mathematics and Further Mathematics fell from 66,247 in 2001 to 53,940 in 2002, a drop of almost 20%. For universities already struggling to find sufficient applicants with A-level mathematics to fill places on engineering and science courses, this massive reduction in numbers was a major blow.

The impact of Curriculum 2000 led to further intensive lobbying from HEIs and professional bodies and the Government finally responded by setting up a national inquiry into post-14 mathematics education. In 2004, the report of this Inquiry, *Making Mathematics Count,* was

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[2] In the early 1990s, the majority of new undergraduates in England entered university having taken A-levels as their final qualification in school. A-levels were graded A-E (pass grades), N (narrow fail), U (unclassified).
[3] Imperial College, London is one of the most prestigious higher education institutions in the UK for the study of science and technology and, as such, able to recruit from amongst the best qualified students.
[4] GCSE is the qualification taken at age 16 i.e. at the end of compulsory study of mathematics in England and is considerably below the level of the A-level qualification.

published [2]. Several of its recommendations were acted upon reasonably quickly (such as the creation of a high-level post in the Department for Education and Science with dedicated subject specific responsibility for mathematics [recommendation 1.1] and the establishment of a National Centre for Excellence in the Teaching of Mathematics [recommendation 6.12]). However, it was clear that it would take several years for the majority of recommendations to be implemented (including those relating to addressing the shortage of well-qualified mathematics teachers) and have an effect on new undergraduates; hence the already quoted conclusion of the Inquiry that, in the short-term, higher education would have to 'accommodate to the students emerging from the current GCE process' 2,p.95].

The technological advances of the 21st century, particularly in the field of computing, led to a rapid increase in the amount of data available and this has affected virtually all disciplines in higher education. Consequently, other bodies (in addition to traditional ones from engineering and the physical sciences) have raised concerns in relation to the mathematical and quantitative skills of the students studying their disciplines. For example, in the biosciences 'UK graduates lack the quantitative skills necessary to analyse and interpret data and to have confidence in their analysis. Some candidates show a lack of even basic mathematical skills' [25,p.14]. Concerns were not restricted to the sciences. In 2012, the British Academy, the UK's national body for the humanities and social sciences, issued a position statement *Society Counts* [10], the opening words of which are:

> The British Academy is deeply concerned that the UK is weak in quantitative skills, in particular but not exclusively in the social sciences and humanities [10,p.1].

This position statement not only speaks of the lack of quantitative skills of students, it extends the Mathematics Problem to academic staff: 'Another reason for the poor skills of undergraduates is the dearth of academic staff able to teach quantitative methods' [10,p.4].

Echoing the titles of earlier reports (but with greater ambition than 'measuring' or 'tackling'), the Royal Society of Arts (RSA) published a report *Solving the maths problem* [26]. One of its conclusions is that

> English universities are side-lining quantitative and mathematical content because students and staff lack the requisite confidence and ability. This has the potential to damage standards in English universities [26,p.11].

Like the British Academy position statement, the RSA report drew attention to the lack of mathematical skills amongst academic staff and the danger of a self-perpetuating situation – students receiving undergraduate education in which mathematical content is side-lined in the fullness of time come to make up the bulk of the academic staff and do not have the confidence to make the curriculum more mathematical.

A key factor contributing to the issues raised in these reports in relation to students is the English secondary education system, where mathematics is compulsory only to age 16

(GCSE-level). Most learners study no mathematics after the age of 16. Hodgen et al. [27] compared upper secondary mathematics education internationally and found that the UK is an outlier. Their work reviewed educational jurisdictions within 24 developed countries and found that in only six of these jurisdictions is mathematics not compulsory after the age of 16 – four of these six were England, Scotland, Wales and Northern Ireland (the other two were Ireland and Australia (NSW)). England, Wales and Northern Ireland were the only jurisdictions where fewer than 20% of upper secondary students studied mathematics.

The impact of this low participation rate in mathematics post-16 was investigated by the Advisory Committee on Mathematics Education (ACME). In their report *Mathematical Needs: Mathematics in the workplace and in higher education* [28,p.1] they state that

> We estimate that of those entering higher education each year, some 330,000 would benefit from recent experience of studying some mathematics (including statistics) at a level beyond GCSE, but fewer than 125,000 have done so.

This gap of 205,000 represents students who are likely to need mathematics support once they enter higher education.

In response to these concerns, Michael Gove, the then Minister of Education, announced in 2011 that he was setting a new goal for the education system that 'within a decade the vast majority of pupils are studying maths right through to the age of 18' [29]. Such goals are easy to set but harder to deliver; in particular, given that the shortage of specialist mathematics teachers highlighted by Smith [2] had not been remedied, it was not clear where the teachers required to implement this policy goal would be found. One key part of the strategy to achieve this has been the introduction of a new qualification, called Core Mathematics, that may be taken post-16 alongside A-levels by students who are not taking A-level mathematics. In 2018, there were 6,849 entries[5] for this qualification, some way short of the 205,000 new undergraduates ACME had identified as needing to study some mathematics beyond GCSE level.

This focus on subjects such as the biosciences, social sciences and humanities should not be taken as a sign that the original mathematics problem raised by engineering and the physical sciences had been solved. In 2011, the Institute of Physics published a report *Mind the Gap: mathematics and the transition from A-levels to physics and engineering degrees* [30]. This report returned to the theme of earlier reports, mentioned above, that mathematics A-level was not preparing students adequately for the demands of engineering and physics degree courses. A House of Lords Select Committee report confirmed this stating:

[5] Source: Mathematics Education Innovation (MEI) http://mei.org.uk/files/pdf/MEI-media-release-level-3-qualifications-August-2018.pdf

> In 2006, the Royal Society argued that the gap between the mathematical skills of students when they entered HE and the mathematical skills needed for STEM[6] first degrees was a problem which had become acute … The evidence we received suggested that the problem remains [31,p.15].

The data explosion and the impending demands of the fourth industrial revolution means that employers are increasingly valuing analytical skills in their graduate recruits [32]. As part of the employment selection process for graduates, many employers now use numerical reasoning tests to assess applicants' analytical skills. Similar numerical reasoning tests had been introduced in 2000 by the Department of Education for all students seeking to gain Qualified Teacher Status. Consequently, even where students have studied one of the few remaining disciplines in higher education with no quantitative skills demand beyond GCSE level, their mathematical abilities will often still be tested as part of the employment process. For students who have not studied any mathematics since the age of 16, this is often a daunting prospect.

Whilst this paper focuses its attention on the position in the United Kingdom, it should be pointed out that the phenomena described above are not unique to the United Kingdom. These issues, or similar ones have been encountered in many countries throughout the world. For example, the opening words of the foreword to a report for the Australian Council of Deans of Science, *The State of Quantitative Skills in Undergraduate Science Education* [33, p.i] are 'The *QS in Science* project raises alarm bells for the higher education sector'. The report itself states

> The lack of quantitative confidence and preparedness among secondary school students is presenting significant challenges to the tertiary sector … Students entering science programs have weaker foundations in, and stronger negative beliefs towards, mathematics but at the same time advances in science and technology require more complex quantitative knowledge and skills [33,p.3].

In Ireland, long-term evaluation of new student preparedness at the University of Limerick, using results from diagnostic testing in a manner similar to previously cited work in England [23], provided evidence of a decline, over a 12 year period, in the mathematical competencies of students entering science and technology courses [34]. The National Council for Curriculum and Assessment instigated a review of mathematics education in secondary education in Ireland stating that the context of the review was a 'fundamental evaluation of the appropriateness of the mathematics that students engage with in school and its relevance to their needs' [35,p.3]. The outcome of this review was the introduction of a new curriculum called Project Maths which was rolled out in schools from 2010.

[6] STEM = Science, Technology, Engineering and Mathematics.

A discussion group at the European Society for Engineering Education (SEFI) Mathematics Working Group addressed the question 'What are the major problems facing Engineering Maths Education in Europe?' [36]. This group concluded that

> The lack of basic skills of university freshmen is well known and seems to be Europe-wide. Participants saw as reasons for this state the expansion of higher education, the lack of training at schools, the abuse of the calculator and also missing qualifications of school teachers [36,p.1].

In summary, the Mathematics Problem has evolved over the last twenty five years. It began as a concern, primarily in engineering and the physical sciences, that good A-level mathematics grades did not signify adequate preparation of students for higher education in the way that they did previously. With the focus on widening participation, the problem grew to include students not being as well qualified (in terms of A-level grades or even not having A-level mathematics at all). The increasing quantification of many disciplines extended the problem still further to include biosciences, social sciences, the humanities and other disciplines where the key element of the Mathematics Problem was that compulsory mathematics education ended at 16 and only a small proportion of students choose to study mathematics post-16. The latest development of the Mathematics Problem (as it exists at present) is the demands of employers for graduates from every discipline to display analytical skills (particularly in relation to numerical data); such skills are viewed as essential for employability in the light of the fourth industrial revolution.

## 3. Users and non-users of mathematics support

### *3.1 User characteristics*

As has been explained, mathematics support had its origins predominantly in responding to the challenges engineering and physical sciences students were facing as they embarked on their university courses. Although the term 'remedial' was never explicitly used, there was a strong motivation to improve the retention rates on these courses, so the primary target audience for mathematics support was students who were at risk of failing their mathematics modules. In the early days of mathematics support therefore, there were three common characteristics of users of mathematics support (at least, in the intentions of those providing the support):

1. They were students of engineering and the physical sciences;
2. They were students newly enrolled in higher education;
3. They were weaker ('at risk') students.

Lawson, Halpin and Croft [37], reporting on a national survey of mathematics support provision, indicated that engineering students were usually the major users. Further reports [38-40] reinforce the focus of mathematics support on engineering and science students.

However, as is explained in Section 2, the nature of the mathematics problem has diversified and expanded since the 1990s and many more disciplines are now requiring students to use quantitative methods to some extent. Consequently, the demand for mathematics support from students of other disciplines has grown. This is reflected in the literature with several articles relating to discipline-specific mathematics support being published covering disciplines such as pharmacy [41], teacher education [42], biosciences [43], business [44] and nursing [45]. In addition, it has also been observed that mathematics students are often major users of mathematics support [46]. For example, Loughborough University's Mathematics Education Centre Annual Reports, cited in [47], show that typically 25 % of the students who visit mathematics support centres are specialist mathematics students. This is explored further in Section 3.3.

The diversification of the subject specialisms of students accessing mathematics support has resulted in more demand for support with statistics. A report from the British Academy [48, p.2] highlighted the 'varying, and often weak, fluency in statistics' and the need for improvements. Statistics support often takes a different form from mathematics support. For students who are undertaking large scale data gathering projects, drop-in support is not an ideal way of addressing their issues. Although some statistical queries (for example, around basic concepts like measures of central tendency and spread or use of normal distribution tables) can be dealt with well through a short consultation with a tutor in a drop-in centre, many others cannot. For example, where a student is carrying out a major data gathering exercise (for example, as part of a final year project) a longer, more concentrated consultation is needed. For this reason, many institutions offer bookable one-to-one appointments of up to one-hour duration for statistics support [49].

In practice, it is not just students with difficulties at the transition into higher education who engage with mathematics support. Whilst the majority of users have been, and continue to be, first year undergraduates, there are other users too. Lawson et al. [37,p.20] record that

> At some universities only foundation and first year students can use the centre (although some indicate that whilst not encouraging others to come they are not actually turned away). More commonly, the support is available to anyone studying a mathematics or statistics module. Finally the most common position is any member of the university can take advantage of the support that is on offer.

Although it was common to make mathematics support available to any member of the university, the expectation was that the overwhelming majority of users would be from foundation and first years. However, this has not always proved to be the case, with some institutions reporting significant engagement with mathematics support by students from later years (for example, [46]). Many students who engage with mathematics support in their first year continue to do so as they progress through their courses. Others who did not encounter serious difficulties with mathematics in their first year, find that the increased level of difficulty in later years means they need to access support. In one institution, 24% of visits to the drop-in centre were from students taking level 3 and level 4 modules (the final two years of undergraduate study) or from postgraduates. This high level of demand, impacted on the service that could be provided to students from levels 0, 1 and 2. As a consequence, it was felt necessary to restrict access to the drop-in centre to students from levels 0, 1 and 2 [49]. Similar circumstances are reported in another institution [50].

Tolley and Mackenzie [51], in their report of interviews of 23 senior university managers, draw attention to the fact that postgraduate students are increasingly facing challenges in relation to mathematics and statistics. One interviewee stated that 'postgraduates are expected to use and understand statistics to a standard they have not been required to do in the past' [51,p.13]. Particularly in the social sciences, the research literature is much more quantitative than undergraduate curricula [10] and postgraduate students need to engage with this literature without the appropriate statistical knowledge and experience.

The third anticipated characteristic of mathematics support users is that they would be predominantly 'at risk' or weaker students. However, this has not been confirmed by a number of studies. Pell and Croft [52] found that mathematics support was used more by good engineering students seeking better marks than by weak students trying to avoid failure. The results of a study of design students showed that those who made use of mathematics support had a slightly weaker mathematics background than those who did not but engagement with mathematics support was not overwhelmingly dominated by weak students [53]. Another study investigated the use of mathematics support by both arts and science students [54]. This found that at-risk first year students were more likely than stronger students to engage, but that it was the stronger second and third year arts students, seeking to improve their chances of achieving first-class marks, who were more likely to access mathematics support than their weaker counterparts. Pell and Croft commented that mathematics support had moved on from 'remedial support to enhancement' [52,p.172], an idea supported by Rogers, who described the change in mission of the mathematics support centre from being somewhat hidden away and focused on students transitioning into higher education to having a centre stage location in the main library and a new mission 'to enhance the mathematical learning of *all students* [our emphasis] throughout the university' [55, p.2].

There has been growing awareness that the diversity encompassed in the phrase 'all students' requires innovative approaches to offering mathematics support. For example, [56,57] explore effective ways of supporting students with dyslexia in their learning of mathematics. Cliffe sets out ways of creating accessible learning environments to enhance the learning of students with a range of physical disabilities [58]. Thus the mathematics support community has recognised that responding effectively to the needs of all students can require variety in the way support is provided and accordingly has developed appropriate mechanisms to deliver this support.

### *3.2 Non-engagement with mathematics support*

Notwithstanding the widening of the mission of mathematics support provision to one of enhancement for all students and not simply remediation or rescue of weaker students, engagement with at risk students still remains an important part of the aims of mathematics support providers. One study draws attention to the fact that many students who would be expected to benefit from mathematics support, and indeed for whom such engagement could be the difference between passing and failing their mathematics module, do not engage [59]. This study identifies reasons for non-engagement as revealed through interviews with and focus groups of non-users. The reasons most frequently given for not accessing mathematics support were not being aware that mathematics support was available and not being aware of the location of the mathematics support provision. Such reasons have been described as ‘shallow’ and it has been suggested that they may mask the real reason [47]. Similar reasons for non-engagement were given by a sample of students from across the island of Ireland [60]. The top two reasons given were that the times when mathematics support was available did not suit and that they did not know where the mathematics support centre was located. In both these studies, a small number of students appear to be either more honest or more self-aware and report reasons for non-engagement with mathematics support such as feeling that they had too many problems, fear of embarrassment, intimidation and demoralisation.

Another focused study of engagement with mathematics support used in-depth individual interviews with two groups of students: users and non-users [61]. This work identified that students’ reactions to critical events are key in determining their engagement with mathematics support. For example, a key critical event was difficulties with assignments. Students from the group that had engaged with mathematics support reacted in a uniform way to such a critical event – they sought assistance, primarily from the mathematics support centre. However students from the group that did not engage with support reacted differently to this critical event – they decreased their assignment submission rates and attendance at tutorials. When asked if she had simply resigned herself to failure, one student said ‘I think I was kind of hoping for some miracle … I just kind of pushed it to the side’ [61,p.14]. This work identifies three factors: fear, social interactions and motivation, as key in determining the way that students respond to critical events.

To address the aforementioned ‘shallow’ reasons for non-engagement, mathematics support providers have used normal marketing methods to make students aware of the services they provide. Posters, advertisements and links on the institutional VLE, social media and lecture shoutouts are commonly employed. In addition, links with initial diagnostic testing, induction week visits, free calculators collected from the drop in centre and free USB sticks containing mathematics support resources included in the university welcome pack have also been trialled.

In recent years some providers have adopted a different approach to secure engagement from those with ‘deep’ reasons for non-engagement. They have adapted the method of providing mathematics support by introducing ‘embedded support’, i.e. moving from an opt-in model to an opt-out one (for example, [44, 62]). Such an approach typically ‘attaches’ to a module a small number of tutorial or workshop sessions which all students are expected to attend. It may be argued that such an approach is not ‘additional’ in the sense of the commonly used definition of mathematics support quoted in the Introduction to this paper [1]. However, this approach has been introduced to accommodate to mathematical difficulties students encounter because of their under-preparedness for their course of study and, as such, it seems reasonable to regard it as mathematics support.

### *3.3 Mathematics support and the specialist student*
Although mathematics support was originally established for students studying disciplines other than the mathematical sciences, as was noted in Section 3.1, in some institutions specialist mathematics students engage extensively with the mathematics support on offer (see also [46]). It has been reported that, at one institution in Australia, specialist students made such extensive use of the support facility (they 'colonised' the space) that the institution provided a separate space for them to use so that the drop-in centre could be more easily accessed by students of other disciplines [63].

A similar phenomenon has been observed in the UK, and the same language of colonisation was used to describe what took place:

> An unforeseen consequence of the Support Centre was the mathematics students' colonisation of the physical space and the development of group learning strategies which involve a strong community identity [64,p.421].

In this institution too, a separate facility was made available for the mathematics students.

In this and later work [65], reasons for this colonisation were explored through a series of interviews with some of the students involved. These interviews revealed that the drop-in centre by its very existence and also because of simple physical factors, such as the furniture consisting of round tables, promoted group working and peer to peer support. It also provided a secure environment for students to work in; secure in the sense that students might not go there seeking help but to work on their own or with each other knowing that if they needed it, help was at hand. The one-to-one or one-to-few nature of the interaction with tutors meant that students who, for reasons of embarrassment or peer pressure, would not ask questions in a lecture room in front of the whole cohort would happily ask questions in the support centre. There was also a change in the power dynamic in the relationship with lecturers. Mathematics students who were reluctant to go to a lecturers' office to seek assistance (even during published office hours), because it was 'their space', were much more willing to ask questions in the drop-in centre (to potentially the same member of staff) because the mathematics support centre was viewed as neutral ground. This work showed that female mathematics students particularly appreciated the approach to learning mathematics that the support centre facilitated and promoted, and one which was different from the stereotypical lone and competitive endeavour.

## 4. Tutoring in mathematics support
In this section we focus on those who deliver mathematics support: the tutors. The two dominant forms of mathematics support are the drop-in centre and the bookable one-to-one appointment. In both of these interactions, the tutor has a key role. A multi-institution

investigation of Lawson et al. (2003, p12) highlighted the importance that users of mathematics support placed on the contact with tutors: ‘It was clear from the interviews with student users that the one-to-one help was the most valued part of every support centre’[1,p.12]. Similarly, in a study of mathematics support in a single institution, it was found that ‘students single out MSC [mathematics support centre] tutors for praise’ [66,p.30]. We will explore the role of the tutor and how it has evolved, who undertakes the tutoring, what training is available and conclude by highlighting a specific issue related to staffing of mathematics support.

### *4.1 The role of the tutor*

As has been explained, the original impetus for the establishment of mathematics support provision in universities was to assist students making the transition from school/college into higher education. In particular, the focus was upon engineering undergraduates, particularly those whose prior education meant that they arrived at universities under-prepared for the mathematical demands of their courses. In light of this, it has been suggested that mathematics and statistics support should be delivered by staff who have expertise at the further education/higher education transition and that ‘ordinary HE lecturers’ will typically not have such expertise and that it might be more appropriate to recruit staff who have taught in the further education (i.e. pre-university) sector [67,p.13]. This echoed the remarks of Sutherland and Dewhurst that ‘the teaching needs are more akin to school teaching and university lecturers are not always the best people to be undertaking additional mathematics teaching and support’ [68,p.21].

However, as we have seen in Section 2, mathematics support has evolved from its early focus on engineering undergraduates making the transition into higher education, rendering the decision about who should tutor more complicated than simply recruiting someone with a further education teaching background. Nowadays, a student seeking mathematics support could be studying any of the wide range of courses that the university offers, and at any level from foundation through to postgraduate. They may have a very strong mathematical background or have studied very little or no mathematics since the age of 16. They may be very confident about their mathematical ability and visit the centre for clarification on some advanced topic. Conversely, they may have mathematics anxiety and be disorientated with regard to their studies. Some will have additional needs and neuro-diversities that affect their learning. The mathematics support tutor will know none of these things before the first encounter. Additionally, tutors usually have no prior knowledge of the questions they are likely to be asked. Consequently, they must be able to think on their feet and be willing to explore and research possible solutions in partnership with the student seeking help. They must try to understand the student’s mathematical problems and then offer guidance, motivation and support to help the student successfully work through their issues. These reasons make it difficult to prepare for sessions. Furthermore, they illustrate how support centre tutoring is very different in nature from mainstream university teaching. Given the broad spectrum of students that mathematics and statistics support serves, tutors have diverse, challenging and vital student-facing roles.

Tutors should be welcoming and non-judgmental. They need to be able to cope with a wide range of mathematical content and able to discuss it at a level appropriate to the student. They need to know how to deal with situations when the subject matter is not known to them. Individually, each of these characteristics brings challenges, but taken together they demonstrate how difficult it is to be a `good' support centre tutor. A key point is that building students' confidence is of huge importance [37] and this is particularly true in the light of findings cited earlier that indicate very large numbers of students embark on university courses with insufficiently developed skills [28].

The required characteristics of a mathematics support tutor have been summarised as follows:

> The tutor must be:
> - Able to deal with any aspect of mathematics or statistics
> - Aware of their applications over a wide range of main subjects
> - An expert analyser and re-synthesiser of students' minds
> - An interpreter of students' class notes
> - Able to create the feel-good factor out of an apparent disaster area [69,p5].

It should be pointed out that this list was written at a time when the focus of mathematics support was the transition from pre-university to university mathematics. It was therefore reasonable to expect tutors to be able to deal with any aspect of mathematics or statistics at this level. As the level of students accessing mathematics support has broadened (as described in Section 3.1) so this required characteristic has become somewhat unreasonable. The other desirable tutor characteristics listed above still remain valid in the broader context within which tutors now operate.

Ireland points out that tutors need to realise that often the student's problems do not lie with the topic for which they are seeking help [70]. She gives as an example a student seeking help with applying the quadratic formula. A perceptive tutor will take time to explore the nature of the difficulty and may identify that the problem is not with the student's understanding of the quadratic formula but rather springs from their inability to manipulate negative numbers confidently and competently. An investigation of tutoring in mathematics support through analysis of video recorded tutor-student interactions found positive features including the use of open questions, corrective questioning, the avoidance of judgmental language and negative non-verbal clues [71].

Croft and Grove re-iterate these themes:

> Providing mathematics support is not about 'telling' the student the answer, but about encouraging them to identify their own mathematical problems, helping them tackle these for themselves with support and guidance, and providing suggestions and strategies for independent study. It requires individuals who are comfortable working on a one-to-one basis, who are patient, able to explain mathematical ideas in multiple

ways, have excellent interpersonal skills, and are able to work with students of a range of abilities and from different disciplinary areas [72,p.12].

### *4.2 The tutors and their development*

Given the complexity of the tutoring task, it is natural to ask who the tutors are. A number of national surveys have sought to address this question as outlined in Table 1 below.

*Insert Table 1 near here*

It should be noted that the percentages in each row of Table 1 sum to more than one hundred since many institutions use more than one type of tutor.

In Table 1, departmental staff refers to academic staff, usually from the mathematics department, who have other mainstream teaching duties as well as providing mathematics support; dedicated staff refers to full-time, part-time or hourly paid staff employed specifically to provide mathematics support. The all-Ireland survey [73] did not distinguish between these types of staff. It did however record that 36% of institutions providing mathematics support have a full-time mathematics support manager/co-ordinator with a further 8% having someone with such duties as a separate part of their contract (i.e. these are dedicated staff as noted in Table 1).

The data in Table 1 imply that in England and Wales there has been a move away from departmental academic staff providing mathematics support and towards the employment of dedicated staff. It is also clear that significant use is made of postgraduate students to deliver mathematics support. The latest survey work found that there were seven institutions where mathematics support is provided *solely* by postgraduate students [62]. These institutions were predominantly research intensive universities.

Given the complexity of the nature of the tutor role, as outlined in Section 3.1, it is perhaps surprising that postgraduates are so widely used in a role that, ideally, requires well-developed teaching skills. It is therefore important to be careful in the recruitment and development of postgraduate mathematics support tutors. Gillard, Robathan, and Wilson's (2011) email survey of 40 UK mathematics support providers identified that one of the disadvantages of using postgraduate students as tutors is their lack of teaching experience. One of the respondents to their survey stated that 'they deliberately recruit PG [postgraduate] tutors with a more accommodating personality' [74,p.48]. In other words, mathematical knowledge alone is not sufficient to make a good postgraduate tutor. A detailed study of postgraduate mathematics support tutors found that these tutors often adopted a didactic style giving minimal opportunities for students to attempt problems or ask questions [75]. This work makes several recommendations relating to the training of postgraduate tutors.

The mathematics support community has, for some time, recognised the importance of tutor training and for over ten years has organized regional tutor training workshops, developing freely available training resources [72]. The 2014 evaluation of mathematics support in

Ireland [76] recommended that the provision of bespoke mathematics support tutor training should be a priority. Subsequently, the Irish Mathematics Learning Support Network secured funding to deliver such training in several locations across Ireland. An evaluation of this training pointed to the importance of team building, as many tutors reported feeling isolated in their work, and highlighted the need to further develop the questioning skills of tutors [77].

Despite the recognition of the importance of tutor training and its availability, recent investigations in the UK [79] and in Ireland [73] both found that only about 50% of institutions which provide mathematics support have tutor training in place. The logistics of arranging such training in a timely manner may be reasons why tutor training is not more widespread.

Although postgraduate tutors need training, there are also benefits in using such tutors. The tutors themselves develop personally and professionally. Some tutors work as volunteers in a support centre because they felt this developed their ability to be good tutorial assistants in mainstream teaching and because they found it personally enriching [63]. Postgraduate tutors can make a significant contribution to policy, practice and resource generation [79]. In a detailed study of nine postgraduate mathematics support tutors, the tutors themselves identify multiple personal benefits including developing a 'more professional' attitude, becoming better not only at teaching but also at mathematics and growing in confidence so that they felt able to suggest changes to university teaching practices [80].

***4.3 A staffing issue***

In the early 1990s, when institutional mathematics support was in its infancy, those who delivered mathematics support were typically academic staff from the mathematics department who provided mathematics support as an adjunct to their main roles of teaching and research. As mathematics support has become more embedded across the higher education sector and larger in scale, the staffing of support provision has diversified as revealed in a number of multi-institution surveys and single institution studies (for example, [66,73,82]).

As shown in Table 1, many institutions now employ dedicated mathematics support managers and/or staff, who may be supported by hourly paid staff and postgraduate tutors who typically contribute a few hours per week. Often many of the staff have fixed-term (typically lasting for a year) contracts because the funding for the mathematics support provision is subject to renewal. The short-term nature of contracts means that many mathematics support staff move on to other positions after a few years as they seek better job security. Furthermore, and as is discussed in more detail in Section 5, in several institutions, responsibility for the provision of mathematics does not lie with the mathematics department but with a central student learning support facility. In such circumstances, it is often the case that mathematics support staff are not on academic contracts. Frequent changes in staffing can impact on the consistency, availability and quality of support [82]. Similar issues are raised in [83].

## 5. The position of mathematics support within HE structures

It is difficult to be precise about when organised mathematics support (as opposed to individual members of academic staff offering ad hoc additional support to their students) began in the UK. It would appear to be in the late 1980s / early 1990s in response to problems identified 'at the chalkface' which were later formally acknowledged within national reports [19,20].

One of the first large scale mathematics support centres was at Coventry Polytechnic (now Coventry University). This was established in 1991 following the receipt of a grant from the oil company BP and focused initially on supporting engineering students [84]. This was an initiative from the mathematics department which was responsible for teaching mathematics to engineering students.

In 1993, the first National Conference on Supporting Mathematics in Further and Higher Education took place at the University of Luton and one of the outcomes of that conference was the establishment of a biannual Mathematics Support Newsletter [85]. Nine issues of this newsletter were published during the period 1994 – 1999. Articles in these newsletters show how mathematics support in universities appeared to be initiated by and be the responsibility of the mathematics department (for example, [24,86]). A survey at this time found that the funding for mathematics support in universities came mainly from mathematics departments, sometimes with additional central funding being provided [87].

It appears that in its early stages of development, mathematics support tended to be provided at a departmental level as a local response to wider national problems. Lane, one of the delegates at the aforementioned first National Conference on Supporting Mathematics in Further and Higher Education, indicated that mathematics support was delivered by 'dedicated enthusiasts struggling to cope with a desperate situation which is getting worse each year, usually with inadequate resources' [88,p.23]. This view of mathematics support being driven by individuals was later echoed by Kyle:

> Although I might not have put it in these terms at the time, I probably regarded mathematics support as a form of cottage industry practised by a few well meaning, possibly eccentric, individuals, who may themselves have been hard pushed to offer a credible rationale for this work [13,p.103].

The Mathematics Support Newsletter covered both Further and Higher Education. The last newsletter was published in 1999 and from then most published scholarship relating to mathematics support focused on higher education. A survey of only the HE sector in 2001 showed that mathematics support was still predominantly departmentally focused, but there were early signs that mathematics support was beginning to move up institutional agendas [37]. For example, 5% of institutions (i.e. 2 institutions) reporting that they had a mathematics support provision indicated that this provision was part of a general student support centre.

In a reflection on lessons learnt in implementing mathematics support, one of the key lessons highlighted is the importance of securing proactive senior management support [89]. However, this work is from the perspective of the need for mathematics support being a local initiative originating in a mathematics or engineering department. This was the original mode of development. But external drivers were leading to the provision of mathematics support becoming an increasingly important strategic priority at institutional level and therefore being initiated and overseen, not just championed, by senior management. For example, at Loughborough University, the Strategic Plan included an aspiration for the Mathematics Education Centre: 'nationally the Centre will be known for leading-edge curricula including cross-campus specialist support in areas such as mathematics and statistics' [90,p.116].

Government policies relating to widening participation referred to earlier in this paper, caused university managers to start to view the provision of mathematics support as more than an issue local to the mathematics department. Widening participation funding was used to set up a mathematics support centre at Nottingham Trent University; this was however a school-level initiative [91]. In contrast, South Bank University took a strategic decision to establish central academic support for all of its students as an indication of the University's commitment to widening participation [67]. This central provision covered English language, study skills, disability and dyslexia support as well as mathematics and statistics support. Although not necessarily focused on widening participation, campus-wide mathematics support at the University of Hull was similarly co-ordinated by a central unit, Study Advice Services, rather than being a departmental or school-level provision [92].

To further promote its widening participation policy, the Government established the Office for Fair Access (OFFA) in 2004. Each English university was required to produce an 'access agreement' which had to be approved by OFFA. The access agreement had to set out how the university was approaching widening participation, not just in terms of recruiting students from under-represented backgrounds but also in terms of ensuring such students successfully completed their studies. At least 14 universities identified in their access agreements that the provision of mathematics support was part of their widening participation strategy [12].

In addition, during the first decade of this century, government policy focused on greater accountability for higher education through agencies such as the Quality Assurance Agency and instruments such as the National Student Survey (NSS) and more lately the Teaching Excellence Framework. Alongside these official measures, several newspapers began to create league tables of universities giving unofficial rankings of institutions by combining a range of publicly available metrics such as NSS scores, drop-out rates, proportion of students achieving 'good degrees' (i.e. a first class or upper second class honours degree) and the proportion of students securing graduate-level employment. This combination of official and unofficial scrutiny forced universities to give more attention to these issues.

A series of interviews with senior managers from 23 universities representing all mission groups within the UK higher education sector showed that

> All of the HEIs questioned reported having students who are challenged by mathematics and statistics … all the universities questioned recognised that unless they provide appropriate forms of learning support for mathematics and statistics it is inevitable that there will be an adverse impact on their students' satisfaction, retention, achievement and employability … mathematics support is now more visible and high-profile within HEIs and is seen as important for enhancing the student experience and aiding success [51,p.2].

A consequence of the greater strategic importance within institutions of mathematics support has often been that it has been moved from being managed and operated by the mathematics department to being part of a wider central student support provision. A survey of the operation of mathematics and statistics support at 48 institutions showed that in 33 institutions (69%), mathematics and statistics support was integrated with other institutional services and concluded that

> The level of integration, collaboration or alignment with other institutional services again reinforces the findings from Tolley and MacKenzie (2015) that institutions are becoming more strategic about how their provision of mathematics and statistics support operates [78,p.178].

The recognition of the strategic importance to a university of mathematics support provision has had both benefits and disadvantages. Previously, those providing mathematics support had reported in national surveys that their on-going existence was somewhat precarious as there was no guarantee of the level of on-going funding [93,94]. However, the integration within wider student support provision appears to make funding more secure and information from the latest survey of mathematics support provision in England and Wales shows evidence of greater longevity of mathematics support in most institutions, with only a very small number closing such provision [62].

On the other hand, the development of mathematics and statistics support may be hindered by being part of wider student support provision. In one survey it was found that in only 13 out of 48 (27%) institutions studied did complete management responsibility for mathematics support lie with an academic department [78]. Frequently this resulted in mathematics support being managed by someone who had no role in actually delivering this support to students. Also, since staff in central support units are not usually on academic contracts, there is a fear that the burgeoning research and scholarship in the field which took place during the early 2000s may be curtailed. It is this research and scholarship which led Kyle to conclude that his previously somewhat dismissive view of mathematics support could no longer be sustained: 'Mathematics support came of age in the first decade of the 21st century. What might once have been described as a cottage industry now plays a respected and widely adopted role in Higher Education' [13,p.104].

## 6. Evaluating the effectiveness of mathematics support

Kyle's observations as to how the acceptance of mathematics support has been influenced by the way in which those involved in its delivery have extended their efforts to include gathering 'data on the way students use such resources and [to] look for optimal strategies for the delivery of this support' [13,p.104]. The mathematics support community has sought evidence-based answers to questions such as 'Do students value mathematics support?' and 'Is mathematics support effective in improving student learning outcomes?' This move towards a scholarly or research-based perspective [47] has contributed to substantial recent growth in the body of research literature relating to the effectiveness of mathematics support.

A comprehensive review of the published literature relating to the evaluation of mathematics support that existed up until the end of 2012 cited some 56 sources and studies [95]. We will not repeat their work here, although we do use their review framework. Instead we highlight a further series of works, published from 2013 onwards, that contain additional evidence of the impact of mathematics support upon learners.

### *6.1 The development of evaluation in mathematics support*

As Matthews et al. note, 'there is general agreement in the MS [mathematics support] community that evaluation is both necessary and possible' [95,p.177]. Evaluation enables those delivering mathematics support to have confidence that what they are doing is making a difference to students and also provides evidence to university management to support the continued funding of such provision [96]. As shown in Section 5, in many institutions the strategic importance of mathematics support has been recognised and funding is relatively secure. As such, the focus for the evaluation of mathematics support has moved from justifying its existence towards identifying optimal strategies for delivery, and the exploration of approaches that better engage those students who are most at risk from a lack of mathematical preparedness or fluency. This exploration of alternative approaches is an indication of ways in which the provision of mathematics support is diversifying and how mathematics support is responding to specific institutional needs [62].

The difficulties of evaluating mathematics support are well known [95]. Studies continue to note the significant challenges of establishing causal relationships [97] and in demonstrating statistically significant findings [98,99]. Indeed, whilst in one study a regression analysis demonstrated that for at-risk students, their qualifications prior to entry, diagnostic tests scores, and either their number of visits or time spent within mathematics support were predictors of their final mathematics grade, these variables did not explain the level of the variance observed within their overall grades [100]. As such, whilst engagement with mathematics support can be shown to be important, its effects cannot be readily isolated from other factors that also influence student success, confidence and motivation.

The majority of published studies cited in [95] referred to usage data (that is who uses mathematics support, when and how often) within their evaluations. It is noted that whilst such data 'may show who is using a MSC and what topics are being discussed…it does not provide any indication of the quality or success of this support or insights into the student experience' [95,p.178]. This is reinforced by Croft who comments that whilst such usage data is relatively easy to collect and analyse, and over a suitable time period, may show trends in demand and usage by learners, it does not provide insight into what occurs within a mathematics support centre, the quality of the student experience, or the impact of mathematics support on student retention or achievement [101]. Some publications (for example, [102,103]) present student feedback as evidence. However, such student comments must be interpreted cautiously as they are rarely negative because many students are grateful for the efforts of staff to help them [52]. There is also now an increasing range of studies that seek to use statistical methodologies to establish causal links between the use of mathematics support and student success rates (for example [45,99,104,105]).

In recent times cross-institutional studies have become increasingly commonplace with the benefit of offering increased insight into how mathematics support operates and its impacts. For example, O'Sullivan et al. [76] present a nine-institution evaluation of mathematics support that captures the views of over 1,600 students; it demonstrates the significant impact mathematics support can have on learners as

> 22% of respondents who had availed of [mathematics support] had considered dropping out of their course due to mathematical difficulties and almost two thirds of these students stated that availing of [mathematics support] had a positive impact on their retention on their course [76,p.11].

The extent and uptake of mathematics support is explored in [62] which shows the extensive engagement now made with mathematics support services by learners across England and Wales; in total, some 85,000 engagements are collectively reported with mathematics support in an academic year by just under 34,000 students. If the situation in England is similar to that quantified in Ireland regarding propensity to drop out, then approximately 7,500 of these students will have considered dropping out due to mathematical difficulties and approximately 5,000 will have been influenced to continue with their studies by the availability of mathematics support.

### *6.2 Impact of mathematics support upon learners*

Several evaluations that demonstrate the impact of mathematics support upon student performance, retention and confidence are cited in [95]; more recent studies continue to reinforce its impact in these areas. Mulligan and Mac an Bhaird comment upon the role of their mathematics support centre in influencing 26 students who had considered dropping out of university due to their mathematical difficulties to remain [66]. Another study not only links the higher retention rates (when compared with national benchmarks) of engineering students to the widespread implementation of mathematics support in the institution, but also reports that there are the associated effects of 'a significant increase in student success for those accessing support…and an increase in student engagement' [106,p.107].

Some studies explore the impact of mathematics support upon mature learners [98,104]. One shows that the average mark amongst a cohort of mechanical engineering students is slightly higher for those who regularly attended mathematics support, and more significantly notes that mature learners are motivated to use it because they 'are not just interested in passing the exams…they wish to gain a deeper understanding of the subject' [98,p.19]. The other found that the majority of mature learners within the study who engaged with mathematics support indicated a positive change in their study habits, and felt either a greater level of confidence, or a change in their attitude, towards mathematics [104]. A further study from within an institution where 'many students are from "non-traditional" backgrounds such as mature-aged, first in family, and Indigenous' [107,p.A-92] compared the level of students' mathematical confidence before and after obtaining mathematics support: 'Different aspects of confidence, as suggested in the literature, were examined, and it was found that there was an increase in the levels of each of them' [107,p.A-91].

A series of articles (for example, [108]) have been published based on the data from a national survey in Ireland [76]. The large scale nature of their survey means there are a number of robust findings about the impact of mathematics support upon learners: 56% of respondents who had made use of it indicated that it had been 'helpful' or 'extremely helpful' to their mathematical confidence; 56% indicated it had 'some' or a 'large' impact upon their performance in class tests or examinations; and, 65% indicated that it had been 'some' or a 'huge' help with the mathematical demands of their course. It is concluded that 'the results of this survey strongly indicate that students identify mathematics support as having a positive impact on their mathematical experience' [108,p.965]. Whilst this paper focuses on first year students studying service mathematics, another study focused on specialist mathematics students and showed that 70% of users reported that mathematics support had impacted upon their success whilst at university [46].

Whilst the provision of mathematics support through a drop-in model remains dominant within higher education, a recent survey has identified that around 70% of institutions responding to their study across England and Wales indicate they are also delivering mathematics support in different ways (often alongside drop-in centres), either via organised lectures or workshops, or through support opportunities embedded within mainstream teaching [62]. Work from Germany [109] investigates four types of mathematics learning support: bridging courses, mathematics support centres, redesigned lectures and support measures that parallel courses. This study explores 44 projects of mathematics learning support, with mathematics support centres being in a relatively small minority compared to the other approaches. In addition to [109], there is a growing body of literature identifying the impact of alternative approaches to mathematics support that extend beyond use of the drop-in model alone.

Little compares two different approaches to supporting student nurses [45]. The first intervention, aimed at learners who did not achieve full marks on an initial foundation numeracy assessment, offered one-to-one or small group support prior to a re-assessment. The second intervention of a workshop and drop-in session focused upon the drug calculations themselves rather than the numeracy aspects alone. It is noted that 'there is stronger evidence for the first intervention having impact…in the second intervention the highest scoring group of students made use of both the workshop and the drop-in' [45,p.43].

Lingham and Baughan describe a similar, and collaborative, workshop-based approach between the mathematics support centre and the careers service to help students prepare for graduate-level numerical reasoning tests [110]. They find that whilst the centre 'has seen fewer "last minute" numerical reasoning test students', the participants at the workshop over the last two years report an increased knowledge and confidence in numerical reasoning as a result of their attendance. They also identify that 66% of the participants at the workshop were female and this aligns with the findings of another study of student use of drop-in provision where 'female students were almost two and a half times more likely to engage with mathematics support than male students' [111,p.297].

Alternative models of mathematics support have been developed for first year science students within a university lacking an institutional mathematics support centre [112]. This voluntary and extra-curricular programme used a blended learning approach, consisting of drop-in sessions, student worksheets and a commercial online tutoring programme, and allowed students to select the learning activities most suitable for them. In addition to students appreciating this flexibility, 90% of the students who completed both the pre- and post-diagnostic tests improved their scores. Amongst students from the first-year chemistry, biology, physics and statistics cohorts, pass rates 'were higher, often by considerable margins, for the groups of those who engaged measurably in the programme' [112,p.860], with differences between participating and non-participating students from chemistry and biology being statistically significant. A follow-on study, considering the results from a survey of students, reports how embedding mathematics within the context of their disciplines not only helped students understand its relevance but had an 'immediate pay-off for participation' [113,p.77]. A similar blended learning support approach for students studying a first-year mathematics subject which assumes no prior mathematical knowledge is presented in [53]. Additional support was offered by an online platform, workshops, and drop-in support. Whilst they provide as evidence of its positive effects the 15% difference in pass rates between those students who made use of the support and those who did not, they also urge a degree of caution by noting 'it was not possible to disentangle support from tutorial attendance and use of the [learning management system] as there is a statistically significant correlation between the three' [113,p.72].

Several studies highlight the importance of students engaging with mathematics support in a meaningful way in order for it to offer observable benefits to them as learners. In [97], an optional mathematics support programme is described; the programme is for engineering students identified as being at high risk of failing a first-year mathematics course in calculus and linear algebra on the basis of either their performance in a prior mathematics module or because they were repeating the course. The programme took the form of a structured one-hour tutorial and incorporated successful support strategies identified from a review of effective practice elsewhere. Their results show that amongst those students who consistently accessed this support, there existed a pass rate of 79% compared with 43% for those who briefly accessed support, and 46% for those who were unsupported. A similar approach to supporting first-year engineering students with their learning of mathematics is described in [99]. Based upon the results of an initial diagnostic test, students were either directed towards a ‘standard mathematics subject’ or a ‘foundation mathematics subject’. Support for those studying the foundation subject was provided by the mathematics support centre and consisted of problem-solving workshops, support workshops, an online question and answer service and drop-in sessions. It was found that almost 60% of students accessed some form of learning support, and amongst those that were high users of this support there existed a significant difference when compared to the no/low users in that ‘their average [learning management system] activity was just over one standard deviation higher and they did better overall in the subject by almost 10 marks’. However, splitting the cohort into different ability groups can cause problems as reported in [114]. Here, different support approaches are used for students with a vocational rather than more traditional academic background. It is noted that some students felt ‘like they had been put in a remedial class’ and ‘perceived that staff had lower expectations, which in turn led to reduced motivation’. Some also reported finding the act of dropping into the mathematics support centre ‘to sometimes be intimidating, due to having “simple” questions in an environment often dominated by students studying more complex topics’ [114,p.25].

The importance of sustained student engagement with mathematics support is evidenced in [105] through analysis of data gathered from the visits of some 10,500 students over 12 years to the mathematics support centre. The results, although requiring a note of caution as they show correlation rather than causation, indicate that ‘the odds of a student who attended mathematics support once passing their module were 1.63 times higher than for one who had never engaged with the service’ but ‘the odds for those who attended 15 or more times were almost 14 times higher’ [105,p.1].

The considerable volume of publications since the seminal literature review paper [95] indicates that evaluation of mathematics support continues to be a live area of research activity. Large-scale studies of ‘traditional’ mathematics support have provided strong evidence of its effectiveness. Alongside these, smaller studies of emerging forms of mathematics support indicate value in these approaches too.

## 7. Conclusions

The sheer extent of the literature relating to mathematics and statistics support is indicative of an active community which is engaging extensively in research and scholarship to seek to enhance the service it provides to learners. Most of the research reviewed is practice-based and innovations that are reported almost exclusively emerge from the professional practice of those involved in delivering support to students, rather than beginning from a theoretical standpoint and seeking to translate theoretical perspectives into practical application. Nonetheless, the widespread scholarly approach to mathematics support has been instrumental in moving mathematics support from the status of 'cottage industry' through 'Cinderella service' and on to its current status of being 'respected and widely adopted'.

In their abstract for a conference talk in 2010, Greenhow and Namestnikova wrote

> Given the changing face of the student population and the views of the various stakeholders in Higher Education (students, parents, government, employers and university staff) that eventually get reflected in league tables and NSS[7]scores, we propose that financially secure, long-lasting and fully-embedded mathematics support will relatively quickly form an unquestioned part of the provision of any well-found university' (cited in [115,p.7]).

The national extent of provision surveys in Australia [116], England and Wales [62], Ireland [73] and Scotland [117] indicate that Greenhow and Namestnikova's proposition has been proved correct within these countries.

One of the strengths of mathematics support being underpinned by practice-based scholarship is that it can be dynamic and responsive. This paper has shown how mathematics support has rapidly evolved to meet the challenges presented by changes to the environment in which it operates. The scale of mathematics support has increased not only in terms of the number of institutions now providing it, but also in terms of both the subject and level of study of the student users. Furthermore, it has evolved from being a remedial service to being about enabling enhancement of learning for all students. One important on-going area of research is 'reaching the hard to reach' or, to put it another way, securing the engagement of those who are reluctant to avail themselves of mathematics support for reasons (such as embarrassment, fear or belief) from the affective rather than the practical domain. Innovative ways of delivering support, such as embedded support are in their infancy, but they offer the prospect of securing some engagement from those who do not respond to the opt-in model of a drop-in centre or bookable appointments.

Staffing of mathematics support appears to be gradually moving from being dominated by academic staff who undertake mathematics support duties as part of their wider academic role to dedicated mathematics support staff aided by postgraduate students. Tutoring in a mathematics support provision is a complex and demanding pedagogical undertaking. Those staff who have a dedicated role may be recruited for their expertise, but postgraduate students need training and, ideally, opportunities for mentoring and peer development to offset their lack of pedagogical experience.

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[7] National Student Survey – an annual Government-mandated student satisfaction survey

External accountability measures, in some jurisdictions at least, have contributed to mathematics support being viewed increasingly as a strategic priority of HEIs, rather than a response to a local departmental difficulty. This has helped achieve Greenhow and Namestnikova's 2010 vision of '*financially secure*' and '*fully-embedded*' mathematics support.

The most fundamental question concerning mathematics support is '*Does it work?*' This is a complex and multi-faceted question which cannot be easily answered. However, as with the other aspects of mathematics support reviewed in this paper, there has been a definite advance in approaches to answering this question over the last twenty years. The seminal large-scale evaluation in Ireland [76] produced the very powerful datum that 63% of mathematics support users who had considered dropping out of university felt that the availability of mathematics learning support had influenced their decision to continue with their studies. Notwithstanding this important finding, robust evaluation of the effectiveness of mathematics support alongside effective ways of engaging the disengaged remain the most important research areas in mathematics support.

## 8. Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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# Tables

| Survey | Nation | Departmental Staff | Dedicated Staff | Postgraduates |
|---|---|---|---|---|
| Lawson et al. [37] | UK | 65% | 41% | 23% |
| Cronin et al. [74] | Ireland | 72% | | 48% |
| Grove et al. [62] | England & Wales | 33% | 63% | 42% |

**Table 1: Percentages of institutions using different kinds of tutors within mathematics support**.

# A2. Professional development opportunities for tutors of mathematics learning support

**Grove, M.J.**, Mac an Bhaird, C. & O'Sullivan, C. (2019). Professional development opportunities for tutors of mathematics learning support. *MSOR Connections*, 18(1), pp. 4-15.

## CASE STUDY

# Professional development opportunities for tutors of mathematics learning support

Michael Grove, School of Mathematics, University of Birmingham, Birmingham, UK. Email: m.j.grove@bham.ac.uk.
Ciarán Mac an Bhaird, Department of Mathematics and Statistics, Maynooth University, Ireland. Email: ciaran.macanbhaird@mu.ie.
Ciarán O'Sullivan, Department of Mechanical Engineering, Technological University Dublin – Tallaght Campus, Dublin, Ireland. Email: Ciaran.OSullivan@TUDublin.ie.

## Abstract

Deficiencies in the mathematical skills of students entering university study are having a negative impact on their education, and more broadly have serious consequences for society as a whole. Research demonstrates that extra initiatives established to give these students an opportunity to succeed are making a difference, and that the staff who provide these supports play a fundamental role. Here we review two different models of structured training that were developed for these tutors, via two cases studies drawn from within the UK and Ireland. We discuss the key and transferrable skills that these tutors require, skills that are often not typically needed in a more 'traditional' teaching role. The majority of tutors remain in this crucial support role for only a short period of their careers, and so a fundamental question remains as to how they can receive appropriate recognition for their academic endeavours. Such recognition is important for both the institution, in demonstrating its commitment to teaching quality, and for the career progression of the tutors themselves.

**Keywords:** mathematics support, tutor training, accredited provision.

## 1. Introduction

Mathematics learning support (MLS) is now a widely accepted means of helping students address the difficulties they encounter with the mathematical and statistical components of their studies, particularly as they make the transition to university study (Lawson, 2015). Student evaluations of MLS provision identify, almost without exception, the crucial role of MLS tutors in their success (O'Sullivan, Mac an Bhaird, Fitzmaurice and Ní Fhloinn, 2014). This reflects the unique MLS student-tutor relationship where one-to-one support is provided in a relaxed and non-threatening environment. Sound mathematical knowledge, and the ability to apply it, are presumed for an MLS tutor. However, the diverse and challenging nature of the teaching involved and the many different situations they may potentially encounter (Croft and Grove, 2011) means that tutors need to be appropriately trained and subsequently supported (mentored) by those with experience of working in such a teaching environment. In recent years, there has been a significant increase in the levels of training available for MLS tutors (Croft and Grove, 2016; Fitzmaurice, Cronin, Ní Fhloinn, O'Sullivan and Walsh, 2016) and this coincides with national moves to increase the number of staff within UK and Irish HE with a recognised teaching qualification. For example Marshall, in her forward to the 2015 UK Student Experience Survey (Buckley, Soilemetzidis and Hillman, 2015), comments on the results (p.3):

> *When asked to rank the importance of three different characteristics of the people they are taught by, students in nearly half of all subjects rate staff having received training in how to teach as the number one priority. When asked last year about priorities for institutional expenditure, a significant number of students chose better training for lecturers.*

In this paper, we focus on the key role of tutors in MLS, and present two case studies of MLS tutor training successfully established (not entirely independently) in the UK and Ireland. These training models are the culmination of a journey from ad hoc (institutional specific) training to structured regional/national models of training.

## 2. Background

The postgraduate teaching assistant, has a well-established and vital role in supporting teaching and learning within HE and one that requires specific support (National Research Council, 1991, p.27):

> *Heavy reliance on the use of graduate teaching assistants, many of whom have limited experience or training for the responsibilities placed on them, has far-reaching consequences…Few graduate students, however, are ready to serve well the educational needs of first-year college students…*

Within the US, there has long been recognition of the importance of the postgraduate teaching assistant within the mathematical sciences. The Mathematical Association of America (MAA) within its *Guidelines for Programs and Departments in Undergraduate Mathematical Sciences* (MAA, 2003), makes it clear that "*since they are the future faculty members of our colleges and universities, it is important that graduate students have some instruction in teaching including serving as apprentice teachers.*" (p.3). Furthermore, it adds: "*Departments should provide long-term structured opportunities for acquisition and improvement of teaching skills by all who teach.*" (p.3). In comparison, perhaps the closest UK equivalent to this, the Quality Assurance Agency (QAA) for Higher Education Subject Benchmark Statement for Mathematics Statistics and Operational Research (QAA, 2015), a document designed to ensure the quality and standards for mathematics education in UK HE, currently makes absolutely no reference to training for those teaching or supporting the mathematical sciences within HE.

Within the UK, a 2005 survey involving approximately 60 postgraduate students from the mathematical sciences and exploring their training needs (Cox and Kyle, 2005) highlighted that most (70%) were involved in running seminars, tutorials, problem classes or other small group teaching of some kind in Mathematics or Statistics, 40% were involved in marking exams and about half marked coursework. Despite the far-reaching nature of their roles, postgraduates were increasingly reporting that they received little training or support for these duties: "*Before embarking on my teaching duties as a postgraduate it always struck me as somewhat unusual that PhD students are able to and expected to be capable of undertaking such duties with very little (or if given) suitable training*" (Lee, 2005, p.38). There are likely to be benefits for the undergraduates who receive the tutoring if the postgraduates have been appropriately trained. The postgraduates are not only better prepared to meet the needs and expectations of the undergraduate students they tutor, but they also develop their own skills, their confidence in teaching and receive a valuable preparation for a range of future academic and non-academic careers.

In more recent times the important role of postgraduate students working within a MLS environment has become increasingly apparent and this is coupled with the widespread growth of mathematics support observed across the UK and Ireland (Perkin, Croft and Lawson, 2013; Cronin et al., 2016). For example, in their analysis of recent surveys of MLS undertaken across the UK and Ireland, Grove, Croft and Lawson (2019) identified that out of 116 institutions, 53 were using postgraduate students as tutors within MLS. Further, amongst the 78 institutions they surveyed in 2018 within England and Wales as part of this work, there were seven institutions where mathematics support was provided solely by postgraduate students.

MLS tutors have diverse mathematical backgrounds (Cronin et al., 2016; Grove, Croft and Lawson, 2019), mainly encompassing postgraduate and undergraduate students, full-time and part-time staff, and staff who are external to the institution. While some of these tutors may have experience gained from traditional teaching roles within the institution such as lecturing or tutoring within a department, MLS tutoring requires an additional and enhanced set of skills. In a sense, it is not tutoring, it is not small group teaching, it requires communication skills, human empathy, and the ability to allow other people to work and fail but within a supportive and non-judgmental environment; it is the ability to guide independent learning. Within MLS, tutors work with some of the most vulnerable students, those lacking confidence, those with specific learning difficulties, and those most at risk of dropping out. Increasingly, MLS is also being accessed by the specialist and more-able student (Grove, Guiry and Croft, 2019; Croft and Grove, 2015), one who is seeking to enhance and develop their mathematical skills and knowledge even further and occasionally beyond the boundaries of their module(s) of study.

While many MLS tutors may have had some prior training as department tutors or lecturers, they are, as noted by Croft and Grove (2016, p.3), "*in the front line of tackling the lack of confidence and skill deficits of students who arrive at support centres looking for help*". In addition to both their content knowledge and their ability to think on their feet (since student queries are rarely predictable in MLS), tutors need to facilitate a social environment where mathematics learning can take place (Solomon, Croft and Lawson, 2010). The importance of providing MLS in a non-judgmental, non-embarrassing and non-threatening environment (Lawson, Croft and Halpin, 2003; O'Sullivan et al., 2014) is key to giving learners an opportunity to talk about their mathematical problems and concerns.

With students themselves now being required to contribute a greater proportion towards the costs of their education within England and Ireland (see for example *Higher Education and Research Act 2017* and Cassells (2016) respectively), there is evidence that their expectations in relation to their learning experience are changing. For example, the 2016 Student Academic Experience Survey (Neves and Hillman, 2016) concludes (p.5):

> *The student experience is still a positive one, but students as consumers are becoming more demanding. They are looking for evidence of value for money and are prepared to put in the effort themselves as long as they feel this is matched by being offered an involved experience with high-quality teaching, staff who continuously develop their skills, and appropriate levels of contact hours for the subject they choose.*

This, and the now well-documented challenges associated with student learning of mathematics within a range of disciplines, has clear implications for how HEIs can best support these learners to ensure that their programme of study not only meets their needs, in terms of future careers or further study, but also their expectations. Tackling this 'mathematics problem' is an area of priority for almost all HEIs within the UK and Ireland and one where MLS and its tutors have a critical role (Cronin et al., 2016; Grove et al., 2018). Many of these tutors are postgraduates, and for postgraduates who choose to work within MLS, while doing so is known to be challenging, there are many benefits. Since many MLS tutors do not remain in MLS provision for their entire careers, they develop an extensive range of transferable skills that should place them at an advantage when seeking employment or an academic career. However, in order for their experience to be a productive and positive one, they require training and ongoing support, with recent evidence demonstrating that they continue to develop as tutors by being part of a community of their peers (Grove and Croft, 2019).

We now move to consider training for staff involved in teaching/tutoring or supporting students in their mathematical learning. Doing so however, raises a more fundamental issue relevant to all disciplines: how can such training be structured and accredited so that there exists an institutional record that training has taken place and that the individuals who participate have a formal and transferable record of their commitment to their professional development? Through our work, we have identified that such training and support may take one of three forms: ad hoc and non-accredited; structured and non-accredited; and, structured and accredited.

Ad hoc training can perhaps be best described as MLS training designed within an individual institution as a one-off event. It would normally be given before a tutor begins in MLS, and provides essential information the tutor needs to manage typical situations that may arise. Structured training would be designed by a network of experienced MLS practitioners from a variety of institutions. It forms a programme, a regular series of activities, mentoring and support, which when combined offers a continued opportunity for tutors to develop and hone their skills. It would also allow for specific issues or challenges encountered to be discussed and advised on.

Non-accredited describes the situation where there is no formal acknowledgement or recognition that an individual has undertaken such training, and as such, there exists no record of their commitment to their professional development in a format which is easy for a tutor to evidence via a C.V. or a transcript of academic achievement. A record in this format is important for the institution and the individual: it demonstrates that training has not only taken place, but also that the individual possesses the required skills and abilities to perform their duties effectively. For the institution, this is important for demonstrating quality assurance while for the individual it can help in showcasing their skills as they look to make the transition to an academic career or employment.

The two case studies that follow, drawn from the UK and Ireland, illustrate structured and non-accredited approaches that evolved to address the initial professional development needs of MLS tutors but which in their present form are not easily amenable to enabling tutors to gain formal accreditation for the skills and expertise developed.

## 3. Case Study 1: Training staff who work in MLS within the UK

For many years there has been significant work within the US to ensure appropriate training, support and guidance for graduate teaching assistants within the mathematical sciences was available, see for example Rishel (1999). However, within the UK, before 2005, there had been very little. In autumn 2005, the Maths, Stats & OR (MSOR) Network, a national government funded disciplinary organisation with the mission of enhancing teaching and learning within the mathematical sciences in UK HE, set about changing this by introducing a series of one-day workshops aimed at postgraduate students who were teaching and supporting learning.

While we choose not to discuss these workshops here, further details of their structure can be found in Grove, Cox and Kyle (2006). They are important since they formed the subsequent model for a one-day workshop programme developed for those new to working in MLS. Through the National HE STEM Programme (Grove, 2013) a network was developed to assist those working in MLS across England and Wales. In 2010, this **sigma** Network (Croft et al., 2015), which sought to increase the extent of MLS provision and to share effective practice, identified there existed a pressing need to provide some form of initial training to the growing number of postgraduate students involved in the provision of front-line mathematics and statistics support to learners.

The training consisted of one-day workshops delivered by experienced members of the MLS community, who worked as facilitators rather than presenters. The focus for these events was clear, they were practical not theoretical. Further, the events were to be role and subject specific, that is, grounded in the reality of the duties tutors were likely to undertake when working in MLS and based firmly within the context of the discipline of mathematics.

Table 1. Format of **sigma** workshops for postgraduates working in MLS.

| Session | Short Description |
|---|---|
| 1. Welcome and introductions | With a view to establishing interaction and identifying common themes, delegates are asked to spend a few minutes considering what they want to learn/gain from the day. |
| 2. Mathematics support – what is it? | Participants are asked to explore ideas for what MLS is and how it is utilised by learners. The purpose is to develop interaction and help delegates obtain an understanding of the context of working in MLS. |
| 3. Problem solving | Participants consider a range of problems in small groups. The purpose is not to solve these, but to consider how they will help guide students using their MSCs. |
| 4. Principles of maths support – do’s and don’ts | Delegates are asked to consider what they might do prior to, during or after working in the MSC. |
| 5. Offering statistics support | Offering support in statistics is different to offering support in mathematics (Croft and Grove, 2016). Advice is provided on how to deal with statistical queries for tutors who are not specialist statisticians. |
| 6. Tutoring in the mathematics drop-in centre – awareness of individual differences and needs | Students using MLS have a range of backgrounds, interests, and learning styles. Guidance is provided on the backgrounds of students who may use MLS with advice on how to support these. |
| 7. Group activity – exploring scenarios | Groups are given several wide-ranging scenarios that have arisen in existing MSCs and asked to discuss how they would respond. |
| 8. Resources and networking with others | A wealth of resources are now available for MLS. This session raises awareness of some of those that are freely available. |
| 9. Question and answer session | A final opportunity for delegates to explore aspects of the workshop in more detail or to have any questions they may have answered. |

Based on participant feedback, three core principles underpinned the delivery of these workshops, and were critical to their success: practice sharing; an informal environment; and, interactivity. Although workshops were open to all working in MLS from across the UK HE sector, basing them within a HEI meant that often the majority of participants were drawn from that institution. Bringing together new tutors, who were typically postgraduates, was an ideal networking and social opportunity, aiding their adjustment to what might be a new place of study and, in terms of their work in MLS, it was critical for building an environment where there were other like-minded individuals they could approach for advice and guidance post-workshop. The workshops were deliberately designed to be informal; it was deemed essential to engage the postgraduates fully in the activities offered, but also allow them the opportunity to shape the overall direction taken within sessions to respond to their particular needs and concerns. The trainers identified that building an informal environment was key to developing this interactivity, and achieving this involves developing the confidence of participants to freely share their views and ideas throughout the workshop. It was highly noticeable that, as a result of the interactive mathematical tasks, interactivity and the willingness of individuals to contribute views and ideas increased throughout the day.

## 4. Case Study 2: Training staff who work in MLS in Ireland

In Ireland, prior to 2009, the training of MLS tutors was developed and provided as a local activity within some of the individual MSCs. A 2008 audit of MLS provision (Gill, O'Donoghue and Johnson, 2008) found that only 2 of the 13 institutions who responded provided formal training for tutors. Due to the success of **sigma** within the UK, the Irish Mathematics Learning Support Network (IMLSN) was established in 2009. The newly formed IMLSN noted similar challenges and issues associated with the training of tutors amongst those institutions with MLS provision. Indeed, in 2011 the initial data analysis of the large-scale multi-institutional student evaluation of MLS (1633 first-year service mathematics students from nine HEIs) (O'Sullivan et al., 2014), the importance of the tutor role in MLS was so strongly identified by the respondents that the IMLSN gave immediate priority to the design of a structured training programme for MLS tutors on the island of Ireland. The training programme comprised of an amalgamation of tutor training materials designed by members of the IMLSN, whilst making suitable use of proven strategies and materials from within the **sigma** guide (Croft and Grove, 2011). A suite of four workshops to be run over one day was developed, as outlined in table 2. Extensive use of **sigma** materials was made for Workshops 1 and 3, and existing tutor training materials were largely used for Workshop 2. Workshop 4 was a combination of material from the UK along with bespoke material developed in Ireland so as to give a voice to the experiences of existing Irish tutors. As an example of the community approach to the development of these workshops, a document with five 'Do's and Don'ts' in MLS was written by an experienced Irish MLS tutor and used for Workshop 4 initially. Subsequently, a survey was developed and distributed across the IMLSN to try and establish the most common Do's and Don'ts in an Irish context, the findings from which were then incorporated into the workshop training materials.

In September 2013 and 2014 a selection of these workshops were piloted in individual HEIs and facilitators of the training commented that they had worked well and were very well received by tutors. However, this suite of workshops had not been implemented in a way that was accessible to all institutions within the IMLSN and so at that stage had limited impact across the IMLSN. In fact, data gathered in April 2015, as part a review of MLS provision within Ireland, showed that tutor training was provided in only 11 of the 25 of institutions with MLS (Cronin et al., 2016). This reinforced the importance of the IMLSN facilitating a co-ordinated tutor training programme, accessible to as many MLS practitioners as possible. Therefore, in 2015 the IMLSN undertook a national project to further build the capacity of MLS tutors in a structured pan-institutional format by implementing the four pilot workshop MLS tutor training programme in a coordinated way, open to all members of the IMLSN, and subsequently to evaluate the programme of workshops and their impact. The National Forum for the Enhancement of Teaching and Learning in Higher Education (National Forum) under its Disciplinary Network Funding funded the project.

In September 2015, the IMLSN conducted their structured but non-accredited tutor training programme in three institutions, with invitations extended to all MLS tutors across all HEIs on the island of Ireland. The training followed that of the previously piloted one-day four-workshop model. Forty-two tutors from six HEIs participated (Fitzmaurice et al., 2016). In September 2016, the training was offered again in a similar format and advertised across the IMLSN membership.

Table 2. Aims and objectives of the four IMLSN workshops for MLS tutors.

| Workshop title | Short Description |
|---|---|
| **1. Mathematics Learning Support**: Why is it important and how can we improve it? | Aim: To outline the typical mathematical ability of students who require MLS and how to interact effectively with them.<br>This workshop should enable tutors to:<br>(i) Recognise that many students enter HE with relatively poor levels of mathematical ability;<br>(ii) Note the mathematical topics where there are clear gaps in student understanding.<br>(iii) Develop ways of dealing with scenarios, which are commonly encountered during MLS sessions. |
| **2. Working with students:** Explaining, Listening, Questioning Skills | Aim: To equip tutors with the skills they need in explaining, listening and questioning so that they will be able to employ positive strategies of engagement with students who seek MLS. This workshop should enable tutors to:<br>(i) Use active listening techniques in working with students in MLS.<br>(ii) Select and use appropriate types of questions in helping students mathematically.<br>(iii) Employ strategies to engage positively with students seeking MLS. |
| **3. Individual differences and needs:** Scenarios you might encounter in mathematics support | Aim: To enhance tutors' awareness of both the implications of the non-academic differences between students and the range of situations that can occur as a result of diverse student approaches to learning. This workshop should enable tutors to:<br>(i) Recognise the importance of individual (non-academic) differences and needs amongst students, to understand how these can impact on student engagement and to be aware of appropriate interaction with the students in these situations.<br>(ii) Be aware of the range of motivational factors and approaches to learning that are adopted by students, and to be able to respond appropriately to the variety of situations that may occur. |
| **4. Developing as a Tutor:** The Do's and Don'ts. | Aim: To establish a framework of knowledge and techniques to enable tutors to develop as tutors in their future work in MLS. This workshop should enable tutors to:<br>(i) Identify the positive impact that MLS can have on students.<br>(ii) Assimilate the insights of experienced tutors of MLS into their practice.<br>(iii) Use techniques of reflection on key competencies to improve their skills as an MLS tutor on an ongoing basis. |

## 5. Discussion

### *5.1. Perception of training*

The workshops developed for postgraduates working in MLS were a natural evolution of those developed for postgraduates who teach. They share many common features in their design and implementation, but most significantly they were delivered at a national level through the funded MSOR and **sigma** Networks; the former no longer exists, and the latter now exists as an unfunded community of practice. Most significantly, both sets of workshops were an example of structured but non-accredited professional development provision.

For each of the MLS workshops that have been run within the UK, delegate feedback has been collected. This has not focused upon obtaining quantitative ranking scores, but instead on obtaining specific comments that can be used to develop the events through a feedback loop. Feedback particularly emphasises the three underpinning principles: practice sharing; an informal environment; and interactivity. For example: ‘clear explanation on things to do, not to do and things to expect - nice mixture of interactive sessions, lots of new resources’; ‘very dynamic, interactive and easy going. Helped me get a bit more confidence as to my ability to be a good tutor’; and, ‘it gave me a list of resources that should help with solving some of the…problems’.

Another key feature of the feedback was that delegates welcomed the opportunity ‘to network’ and ‘share ideas‘. This is a clear indication of the importance of providing such training provision through a network particularly as within a number of institutions providing mathematics support is known to be a solitary endeavour (Grove, Croft and Lawson, 2019). Typical feedback includes: ‘opportunity for group discussion on individual problems in own maths/stats support centre’; ‘sharing experiences with other people – knowing about what other universities are offering and the methods of support available’; ‘interaction with other would be tutors – advice from lecturers on how to aid others’; and, ‘the brainstorming part of the event was important in terms of knowing each other’s approach in dealing with different scenarios that may occur. Lateral thinking approach to solving questions that might be asked was equally important’.

### *5.2. Impact of training*

While this immediate feedback is reassuring, a key question remains as to whether the training continues to influence postgraduate tutoring practices when working with undergraduates in the medium to longer-term. For the UK model discussed above, there exists some evidence that those postgraduates who have participated in the training have used this to inform their approach to teaching. For example, the following quotes are from undergraduates who received MLS in the academic year 2016/17 within an institution where a compulsory training programme was run for all postgraduates involved in providing MLS; these quotes were taken between one and eight months after the initial training session and refer explicitly to the tutors who provided the support: ‘explained things clearly, talked through steps well, gave good examples to help understanding’, ‘good communication, started from my knowledge so I knew what was going on’, ‘very good help, got me to the answers without giving away too much and explaining theory’, and ‘very helpful, made sure I understood by giving me time to work through problem independently after thorough explanation’.

Within Ireland, focus groups were conducted with postgraduates 10 weeks after the September 2015 training programme. Full details of the results of these are available in Fitzmaurice et al. (2016) but some of their key insights follow here. Tutors reported that the training programme was beneficial for their tutoring practice, and many recommended making it compulsory. Tutors were asked for suggestions on ways the training process could be enhanced for all practicing and prospective tutors. They suggested that: more time be dedicated to the development of tutors’ questioning and assessment skills; they would like more training in teaching group/tutorial sessions. Furthermore, tutors requested greater use of role-playing of MLS scenarios be used in certain workshops.

As outlined previously, the Irish MLS tutor training events in 2015 occurred in three specific HEIs, and tutors from other HEIs were invited to attend. This system helped to establish a sense of community amongst all the tutors, and went some way towards addressing the feelings of isolation that some tutors reported while working in MLS. Tutors highlighted the importance of developing a mechanism to enable them to get to know other tutors, and allow them to feel as part of a team. The importance of these views are reinforced by the findings of more recent work (Grove and Croft, 2019).

Based on the evidence collected to date, the models described above would seem to address the substance of the initial training needs of staff who will work in MLS. Institutions should benefit significantly from employing such suitably trained tutors. Some evidence appears to indicate that tutors have benefited from the training, and as such have a range of skills that will greatly aid their progression to academic, or indeed a range of other diverse careers. However, accreditation is required to ensure that there is demonstrable validation to this effect.

## 6. Conclusions and next steps

The UK workshops were designed as stand-alone events which were non-accredited, however there is some limited evidence that HEIs are accepting these in lieu of more generic forms of institutional training for postgraduates involved in teaching and supporting learning. For example, at the University of Birmingham all postgraduates involved in teaching must receive appropriate training and support. From 2016, the School of Mathematics agreed with the Centre for Learning and Academic Development, the organisation that offers centralised training to postgraduates from any discipline, that participating in a one-day event of the nature described can be accepted in lieu of three of the four generic courses that postgraduates would otherwise attend. Establishing the equivalence of these mathematics-specific activities with their institutional counterparts has been achieved through the mapping of the provision against the UK Professional Standards Framework (UKPSF, 2011) and then establishing its equivalence with existing provision within the institution.

The Irish training programme of workshops for MLS tutors was devised by the IMLSN and as such offers the opportunity for delivery in a wide number of institutions across a network which brings many benefits. However, the IMLSN forms an organisation that is in essence a community of practice and not one that is aligned to any professional development standards – in itself, it has no mechanism for accrediting its own, or indeed anyone else's training provision. The training workshops were structured and based upon individual institutional tutor training materials (some of these formed parts of accredited programmes) and certain key aspects of the **sigma** training, but nevertheless, they were non-accredited.

For the benefit of tutors who are at the front-line of providing a vital student focused service, and indeed their institutions who are now required to demonstrate a clear commitment to furthering teaching excellence, the current lack of accreditation of their training is a situation that needs to change to ensure tutors get the recognition their endeavours deserve. In the context of more highly developed structures of professional development, how to evolve from the structured and unaccredited training to one that is structured and can gain accreditation for the participant forms the next key challenge.

To meet this challenge, the authors have designed a model of tutor development that may be amenable to accreditation which is currently undergoing piloting within Ireland. Work on this model began in 2016 arising from discussions regarding tutor training in light of a newly published framework for professional development in HE in Ireland (National Forum, 2016), which took place at the 10th IMLSN annual conference (IMLSN 10) which was held in Galway, Ireland (Pfeiffer, Cronin and Mac an Bhaird, 2016). The essence of the model is to provide formal recognition for the professional development undertaken by an MLS tutor in a way that the tutor can then seek accreditation from their institution or a professional body. The model provides the potential to move from existing structured and non-accredited models to a structured and accredited model via a formal recognition step which makes use of micro-credentials. At the heart of the model are four micro-credentials: MLS Knowledge and Skills; MLS Communication/Dialogue skills; MLS Professional

Identity Development; MLS Digital Capacity. The micro-credentials can be stored and shared digitally by the tutor awarded them. Each micro-credential contains a description of the abilities which the tutor must develop and a description of the evidence that they must provide to show that they have demonstrated these abilities. The micro-credentials have been designed to equate to 5 ECTs post-graduate credits once all four have been completed. The MLS micro-credential model is designed to allow for delivery through a community of practice which ensures the training is provided by those with the most appropriate teaching knowledge, experience and expertise in the discipline, something not all institutions will have access to. Simultaneously the model could allow a national organisation to offer formal accreditation for the training against a universally recognised framework, for example the UKPSF, whilst also facilitating institutions to understand the equivalence of the activities undertaken and much more easily allow them to be recognised as an appropriate form of prior learning. Piloting of the micro-credentials is ongoing and initial tutor feedback has been positive so the model may form the future basis for tutor training that is structured and can gain accreditation for the participant. We intend to report on the micro-credential based model and the outcomes of this pilot in the near future.

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# A3. Approaches to feedback in the mathematical sciences: just what do students really think?

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# Approaches to feedback in the mathematical sciences: just what do students really think?

MICHAEL J. GROVE* AND CHRIS GOOD
*School of Mathematics, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK*

**Corresponding author. Email:* m.j.grove@bham.ac.uk

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## Abstract

**Assessment and feedback is an area where mathematical sciences departments have invested significant effort in recent times. Particular challenges have been identified relating to timely and detailed feedback, both of which are important given the widespread use of formative, and typically weekly, problem sheet assessments to aid and structure the mathematical development of learners. Here, we report on a first cycle of action research, linked to the implementation of a revised curriculum in a large UK research-intensive mathematical sciences department, which was designed to enhance the feedback received by students and their subsequent engagement with it. Whilst we draw upon the results of a survey of 74 undergraduate students, we also describe the pilot of a method for providing video-based marking and feedback. Our results show the importance that students within the mathematical sciences place upon feedback as part of their learning experience, but also that amongst those undergraduates surveyed, there was no clear consensus as to whether they had received sufficient feedback upon their work. The findings reinforce the need for students themselves to engage with their mathematical feedback in a meaningful way, and significantly they indicate that the feedback perceived as most valuable involves opportunities to engage in dialogue about their work with either their peers, postgraduate teaching assistants or academic members of staff. As such, the emphasis that departments place upon providing 'detailed written comments' on formative work appears not to be valid, and instead more 'dialogical' or 'interactive' mechanisms for providing feedback in mathematics may have the potential to yield more effective results.**

## 1. Introduction

Discussions of assessment in mathematics are often focused upon that of the unseen closed-book examination which is known to dominate current assessment practices. For example, in their 2011 review of undergraduate mathematics assessment, Iannone & Simpson (2011, p4) investigated a total of 1843 modules and noted that '*over one quarter of the modules (535) in the sample are assessed entirely by closed book examination and nearly 70% of the modules (1267) use closed book examinations* *for at least three quarters of the final mark.*' Focusing such a discussion upon the unseen closed-book examination, however, belies the importance of a more dominant form of assessment vital to supporting the mathematical development of students: the problem or exercise sheet.

Problem sheets, as we shall choose to refer to them from now on, form a key part of the undergraduate mathematical sciences curriculum with many universities distributing these on a weekly basis and students devoting a significant part of their time outside of core teaching hours working to complete them. The intended purpose of problem sheets is to help students '*understand and appreciate definitions and theorems mentioned in lectures, applying them in what are for students, novel contexts . . . they most often build on or activate book-work from the course*.' (Badger *et al*. 2012, p40) Whilst they may have a nominal level of credit associated with them, typically to incentivize their completion and submission, and often contributing towards the overall grade at a module level, their primary purpose is formative which means that the feedback provided can be used to '*shape and improve the student's competence by short-circuiting the randomness and inefficiency of trial-and-error learning*.' (Sadler, 1989, p120) In mathematics, if used effectively, problem sheets form a critical mechanism by which learners can help structure and judge their own mathematical development and progress.

Feedback is an essential part of the formative assessment process, providing the student with information about how successfully an activity has been completed. Underpinning this is the role of the teacher who '*knows which skills are to be learned, and who can recognize and describe a fine performance, demonstrate a fine performance, and indicate how a poor performance can be improved*.' (Sadler, 1989, p120) However, comments by a teacher that highlight the strengths and weaknesses of a piece of work are, by themselves, insufficient. There must be engagement by the student with the feedback to allow them to reflect upon their own learning, identify where, and how, they can improve, and perform an analysis of their own skills and abilities. While there exist a range of studies exploring how students use the feedback they receive (see for example Orsmond & Merry, 2011; Steen-Utheim & Hopfenbeck, 2019), as Winstone *et al*. (2017, p17) argue '*there is increasing consensus that a critical determinant of feedback effectiveness is the quality of learners' engagement with, and use of, the feedback they receive.*' This has led some (see for example Yorke, 2003) to suggest that in addition to enhancing the quality of feedback provided, teachers should also focus their efforts upon strengthening the self-analysis skills of their students. As Sadler argues, for a student to have an understanding of the standard being aimed for, to be able to compare their own performance with that standard, and then engage in action to close the performance gap, they must '*possess some of the same evaluative skills as their teacher*.' (as cited in Nicol & Macfarlane-Dick, 2006, p204)

The role of feedback in the learning process is vital as '*few physical, intellectual or social skills can be acquired satisfactorily simply through being told about them*.' (Sadler, 1989, p120) As such, there have been a number of studies exploring the impact of feedback upon the student learning experience across a range of education sectors. In their review article, Black & Wiliam (1998) analyzed over 250 studies of formative assessment coupled with feedback and identified that positive benefits were noted across a range of subjects, student abilities and levels of education. Whilst other studies have commented that '*a limited body of scientifically based empirical evidence exists to support that formative assessment directly contributes to positive educational outcomes*', they too have concluded '*the research discussed in the Black & Wiliam's (1998) review and the other research discussed here does provide some support for the impact of formative assessment on student achievement*.' (Dunn & Mulvenon, 2009, p1,p9)

In a more recent review, Evans (2013, p106) analyzed over 450 articles exploring assessment feedback within higher education. This review reinforced that assessment feedback can enhance student performance, but noted caution as this is '*not in every context and not for all students*'. Most significantly, the analysis of Evans (2013, p106) highlighted that while '*some principles of effective assessment*

TABLE 1. *Percentage of students who indicated they either 'definitely agree' or 'mostly agree' with questions 5–9 and 22 within the 2011 National Student Survey (from HEA, 2012). The number of responses range from 236,544–259,188 (all subjects) to 4,278–5,137 (mathematics only)*

| | Mathematics only | All subjects (excluding mathematics) |
|---|---|---|
| 5. The criteria used in marking have been clear in advance | 73.6% | 73.1% |
| 6. Assessment arrangements and marking have been fair | 84.0% | 74.2% |
| 7. Feedback on my work has been prompt | 74.0% | 62.4% |
| 8. I have received detailed comments on my work | 59.4% | 67.0% |
| 9. Feedback on my work has helped me clarify things I did not understand | 63.4% | 61.4% |
| 22. Overall, I am satisfied with the quality of the course | 88.2% | 83.0% |

TABLE 2. *Percentage of students who indicated they either 'definitely agree' or 'mostly agree' with questions 8–11 and 27 within the 2017 National Student Survey (from HEFCE, 2017). The number of responses range from 318,930–319,180 (all subjects) to 5,618–5,626 (mathematical sciences)*

| | Mathematical sciences | All subjects (including mathematical sciences) |
|---|---|---|
| 8. The criteria used in marking have been clear in advance | 74.9% | 73.2% |
| 9. Marking and assessment has been fair | 84.4% | 73.4% |
| 10. Feedback on my work has been timely | 82.3% | 73.2% |
| 11. I have received helpful comments on my work | 74.3% | 74.3% |
| 27. Overall, I am satisfied with the quality of the course | 88.7% | 84.5% |

*feedback design have been established, the implementation of such designs has been demonstrably more problematic*'. This challenge in implementing effective feedback is not in itself surprising. In the study undertaken by Carless (2006, p230) of written feedback on assignments, a recurring finding was the different perspectives that students hold, when compared to staff members, on elements of the assessment and feedback process, and that '*these perceptions represent a key challenge to enhancing assessment and feedback practices*'. As Carless (2006, p220) notes, one possible mechanism for overcoming these differing perceptions is through '"*Assessment dialogues*" *between tutors and students*'. Here, the emphasis is not on discussing either the subject content or what students need to do in order to be successful in a particular assignment, but more on discussing the assessment process as a general concept. This indicates that work to enhance student perceptions of feedback may be better targeted at a programme or module level, rather than on the basis of each individual assignment.

The research evidence (Evans, 2013; Black & Wiliam, 1998) notes the positive impact that feedback can have upon the learning experience, but significantly it is the students themselves who are now able to comment upon the quality, quantity and timeliness of the feedback they receive in a national context. The key mechanism for this is the National Student Survey (NSS), first launched in 2005, which collects feedback, via a survey, from final year undergraduate students in the UK on their experiences of various aspects of their courses. For the 2017 NSS, the structure and wording of the questions were revised, particularly in relation to assessment and feedback. Whilst this does render any attempt to make direct comparisons with previous years invalid, it is interesting to explore the responses in the mathematical sciences in 2011 (Table 1) with those in 2017 (Table 2).

The data in Table 1 are taken directly from a 2012 Higher Education Academy report (HEA, 2012), whereas those in Table 2 have been compiled from data made available by the Higher Education Funding

Council for England (HEFCE, 2017). For Table 2, whilst there are limitations in the analysis (for example they were compiled from summary data rather than original data), it is the broad trends that are important. Indeed as noted by Hewson (2011, p28) in his analysis of NSS data, '*the brief findings reported here have to be interpreted with great caution, but they are intriguing*'.

Whilst the revised wording of the question itself could be a factor, it is interesting to see that students do seem to be reporting they are now more satisfied with the speed of provision of their feedback. With students themselves now contributing a greater proportion of the costs of their education (up to £9,000 per annum in England from 2012), and with a national move towards more student-focused teaching excellence (DfE, 2017), institutions are increasingly using metrics like the NSS as both a driver, and a measure, of change. There has been significant activity to increase NSS scores within the mathematical sciences in the category of 'Assessment and Feedback', yet, as Table 2 clearly shows, there remains more to be done in providing feedback that students themselves deem to be 'helpful'. In addition, while Small & Attree (2015, p2078) note that students are becoming '*more self-reflective learners using feedback rubrics to compare their assessment with the academic comments...there are still issues of power imbalance as students may still be unwilling to contact academics if the feedback requires clarification*'. As such further work is needed to empower students themselves to better act upon the feedback they receive as part of their own learning experience.

Whilst we describe here an initiative to enhance student feedback, and the subsequent engagement with it by students, this work was not undertaken in isolation. Through the National HE STEM Programme (See Grove, 2013), a project involving over 30 academic staff and approximately 850 students explored feedback practices in the mathematical sciences. The outcomes from this work are described in Robinson (2015). In addition to providing an excellent overview of feedback in the context of the mathematical sciences, it identifies 10 possible aims of feedback, discusses examples of good or innovative practice and offers helpful suggestions for departments to enhance the feedback they provide.

In his suggestions for enhancing feedback, Robinson (2015) highlights a tension between providing feedback that is detailed and feedback that is timely; a clear distinction noted in the NSS. This tension is not new. Timely feedback was highlighted by Chickering & Gamson (1987) as one of their seven principles of good practice in undergraduate education, with students known to particularly value this timeliness since the work will still be fresh in their minds (Poulos & Mahony, 2008). However, as Gibbs & Simpson (2005) comment, resource pressures within higher education are resulting in feedback being provided more slowly, and that efforts in providing feedback after a course has ended are likely to be wasted. Gibbs & Simpson (2005, p19) go on to suggest that '*imperfect feedback from a fellow student provided almost immediately may have much more impact than more perfect feedback from a tutor four weeks later*'. As such, the work we describe here has sought to address the dual motivation of providing feedback of a sufficient quality and quantity to aid learning, but which is also delivered in a timely manner such that it can influence a student's future performance on problem sheet assessments that may be set only 1 or 2 weeks after the previous submission.

Within the mathematical sciences, and indeed other STEM (science, technology, engineering and mathematics) and non-STEM disciplines, many students experience challenges associated with their learning of mathematics as they make the transition to university study. Lawson (2015, p43) provides a comprehensive discussion of these issues and the evidence for them, but factors include the procedural nature of A-level mathematics, a '*lack of mathematical resilience allied to less intrinsic liking of the subject than [they] realised*', and academic staff having '*unrealistic expectations of their students*'. Through a series of linked studies, Williams (2015) investigated student trajectories in and through mathematics programmes from school, through college to higher education. In one aspect of the research, students were asked about their feelings regarding their transition from school to university and were also asked to compare their opportunities to ask questions and discuss ideas at university compared with school. These findings led Williams (2015, p28) to conclude '*that negative feelings are generally associated with a perception of poorer dialogue when students enter university programmes, and vice versa*'. This was reinforced by subsequent interviews and collected case studies which also noted that students making the transition found their interactions with academic staff were fewer and less engaging than they expected (Williams, 2015).

Such transitional issues are not restricted to the school–university interface. As Croft & Grove (2015) note, there are many independent research studies that report a decrease in the enjoyment and engagement with the subject by specialist mathematics students as their studies progress. Often the students who report these feelings '*are not failing students—indeed many are doing rather well*' (Croft & Grove, 2015, p173). It is particularly interesting to note that in their recommendations for enhancing the second-year experience for such students, all of Croft & Grove's (2015) suggestions involve opportunities for increased interaction and dialogue between students and academic staff further reinforcing the importance of the findings of Williams (2015).

## 2. Background

The motivation for the work we describe here was to enhance undergraduate feedback in mathematics, but it formed part of a much wider development. During the 2010/11 academic year, a full-scale review of the undergraduate mathematics curriculum was undertaken within a large research-intensive mathematics department within the UK. Whilst a key focus for this was to enhance the graduate skills, employability and career awareness of students, it also provided an opportunity to consider the curriculum structure, assessment arrangements and support opportunities available to learners, particularly during years 1 and 2. Such a broad focus was a deliberate attempt to help address some of the well known and documented challenges experienced by students in transition described earlier in Section 1.

In an attempt to mitigate these challenges for our learners, a series of interventions were established in the immediate academic years following the curriculum review. Their purpose was to enhance student opportunities for formative feedback, a need identified within departmental NSS scores, by enabling increased dialogue about their learning with peers, postgraduate teaching assistants (PGTAs) and academic members of staff.

### *2.1. The establishment of a tutorial programme*

The weekly compulsory tutorial programme introduced in year 1 was intended as a means of helping all single and joint honours mathematics students adjust to the different nature of university study, but also as a mechanism for providing feedback on the weekly formative problem sheets. Students received a problem sheet on a Wednesday, submitted their solutions for marking by PGTAs exactly 1 week later, with work being returned to learners at the tutorial on either the Thursday or Friday of the following week. As such, the period between submission and return of feedback was a maximum of seven working days. Academic members of staff acted as a tutor to an allocated tutorial group, typically 12 students who they saw for an hour each week in groups of 6, with PGTAs returning student work directly to tutors. Each tutor therefore had an opportunity to review the progress of their tutees before the tutorial and to plan the topics for discussion. The tutorials were student-led, but their purpose was to enable detailed discussion of the problem sheets and the associated mathematical concepts and ideas, and for students to receive further feedback in addition to the comments written by PGTAs on their work and the available worked solutions. In year 2, the format differed slightly as whilst tutorials remained compulsory, assessed problem sheets were returned directly to students, and tutorials alternated between a problem sheet (based around one of the core modules taken by all undergraduates) intended for discussion during the tutorial and professional development activities designed to encourage students to prepare for life after their undergraduate studies.

### *2.2. Subject-specific training for postgraduate students involved in supporting student learning*

Problem sheets are the most dominant method of formative assessment within the mathematical sciences, and typically within the early years of undergraduate programmes they are marked by PGTAs using a mark scheme and worked solutions provided by an academic member of staff. Postgraduates also have an important role in supporting the delivery of workshop-style classes, which in this case were delivered prior to the submission deadline allowing students to discuss the problem sheets and their associated mathematical ideas. Whilst it is typically the case in many departments that PGTAs will receive a level of training before commencing their teaching duties, this is often generic in nature. In an attempt to address some of the student feedback regarding the level of support that they receive with their learning from the PGTAs, we chose to embed a disciplinary model of training, taking place at the start of each academic year, and ongoing support based upon a model that ran nationally for many years (and described in Cox & Kyle, 2005). This training replaced all but a single 2-hour module of generic training and focused upon encouraging and supporting PGTAs to engage in dialogue with students about their mathematical learning. In addition, a further focus of the training was upon marking student work, and in particular establishing expectations within the PGTAs around their provision of feedback.

### *2.3. A University-wide mathematics support centre and Peer-Assisted Study Support (PASS) sessions*

One popular and evidence-based response to supporting students with their learning of mathematics as they begin their university studies is the mathematics support centre. Croft *et al*. (2015) provide a detailed discussion of mathematics support and its origins, but a mathematics support centre comprises a physical location, in our case based within the main university library, where students can drop-in at any time during its hours of opening to receive advice on mathematical queries. This is in addition to the support they receive as part of their undergraduate programme. Mathematical support is provided by tutors, and these are postgraduate mathematics students who have identified they wish to work in the centre, possess the skills and abilities to do so (i.e. the recruitment process is selective), and who then receive additional training and mentoring support (see for example Croft & Grove, 2016). Whilst student users may attend in groups, the experience is personal and driven by the individual student; indeed '*one of the key benefits of this approach recognized by students is the ability to engage in individual mathematical dialogue with a tutor about their learning*' (Grove *et al*. 2019a, p49). From January 2015, the hours of support available in the mathematics support centre during term time were increased from 15 to 30 hours per week. Whilst the centre was established to support learners from all disciplines making the transition to university, in the academic year 2016/17 of the 980 visits made by students, 80% were by mathematics students, and of all visits, almost two-thirds were made by mathematics students in either year 2 or beyond (Grove *et al*. 2019b).

A somewhat related Peer-Assisted Study Scheme (PASS) initiative was also established within the department. Such schemes (Walker, 2015) recognize that, in many cases, students feel more comfortable asking questions of fellow students. Here students from years 2, 3 and 4 volunteered to act as PASS Leaders and provided up to 5 hours of mathematical support per week during term time to their fellow students and typically to those in year 1.

### 2.4. *New module developments and video-based feedback*

More broadly, through the curriculum review described earlier, there existed a strong desire and rationale within the department for providing increased opportunities for students to develop the skills of mathematical modelling and problem solving (Savage & Grove, 2015) coupled with developing their wider employability skills and careers awareness (Waldock & Hibberd, 2015). Two new modules, compulsory for all single honours (specialist) mathematics students, were established: Mathematical Modelling and Problem Solving (year 1) and Mathematics in Industry (year 2). Whilst we choose not to discuss these in detail here, they possess a number of features highly relevant to our work on feedback. Both modules focus upon students completing authentic modelling and problem solving tasks in a workshop-style environment, but doing so as part of a team, and producing their findings in a variety of different formats. In addition to the extensive peer–peer dialogue this approach fosters, a large amount of personalized support is available from the module lecturer (within and outside of the sessions) and from postgraduate teaching assistants acting as advisors to a small number of groups with whom they work closely throughout the formal sessions. Most significantly, as both modules are assessed completely through in-course assessment, it was possible to naturally embed new approaches to providing feedback on the summative tasks, particularly as this feedback could then be used by the student to inform their subsequent submissions.

With financial support from the University, video-based feedback was embedded within both modules to explore whether students felt this enabled them to receive more detailed feedback upon their submitted mathematical work. In this approach, students uploaded their work directly to the virtual learning environment (VLE), and PGTA markers captured the computer screen as they annotated student work and provided an accompanying audio commentary. This video-based feedback, on either an individual or group submission, was then returned to students via a video link uploaded to the VLE. The financial support also enabled video-based feedback to be trialled with the in-course (formative) tasks of a year 3 module, and for a small-scale pilot of using this approach with year 1 weekly problem sheets. It also allowed two student interns to be employed for approximately 8 weeks during the summers of 2014 and 2015. The interns worked on a range of activities, including gathering student perspectives of feedback, but most significantly they trialled and evaluated several approaches to providing audio and video-based feedback, along with producing staff and student guides on providing feedback (Collis & Sivantharajah, 2014a) and utilizing feedback (Collis & Sivantharajah, 2014b). This latter guide includes an interactive activity now embedded in the tutorial programme to allow students to better understand the purposes of feedback and the feedback they receive, and to begin to develop their skills to then use this more effectively in support of their own mathematical development.

## 3. Research methodology

When seeking to explore the impact of a change in practice, an appropriate methodology is one of action research. Cohen *et al*. (2000) provide a comprehensive overview of action research and its origins as a means of enquiry, but a key underlying principle noted by Kemmis & McTaggart (1992) is that it forms an approach to improving education by changing it and through learning from the consequences of those

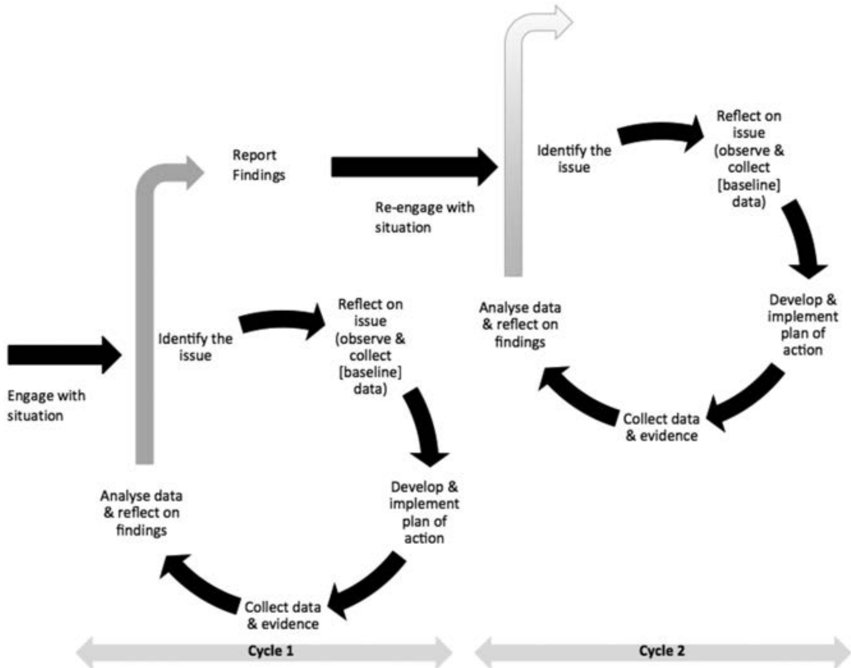


FIG. 1. The action research spiral.

changes. While Kemmis & McTaggart (1992) distinguish action research from the practice of teaching, there exists a close connection between the two as noted by Zeni (1998, p208): '*Action research involves practitioners studying their own professional practice and framing their own questions. Their research has the immediate goal to assess, develop or improve their practice. Such research activities belong to the daily process of good teaching*. . ..' It is this close connection between 'action' and 'research' that not only makes action research unique but also attractive to practitioners, and most significantly accessible to those who may be new to the whole process of educational enquiry. Indeed in the action research-based approach to educational enquiry in mathematics described by Grove & Kyle (2014), a direct analogy is made with the approach to disciplinary research in the mathematical sciences.

Action research develops through a '*self-reflective spiral*' and consists of a spiral of cycles involving: '*planning, acting (implementing plans), observing (systematically), reflecting...and then replanning, further implementation, observing and reflecting.*' (McTaggart, 1997, p34) It may be represented diagrammatically as shown within Fig. 1 which has been developed to demonstrate the action research cycle implemented here.

Described here are the results from the first cycle of action research. Whilst some initial data were collected through the student internship programme (Collis & Sivantharajah, 2014a), this was not intended to provide a formal baseline, but more context to inform the development of a staff handbook. Nevertheless, their results are interesting as they highlight that almost 40% of the students they surveyed rated their feedback as either average or poor (as we shall see, this is in line with our own findings), thereby validating the need for both an intervention and further study.

In Summer 2016, an online survey consisting of 17 questions (listed in Appendix) was undertaken and aimed at single and joint honours students (n∼800) from all 4 years studying for an undergraduate

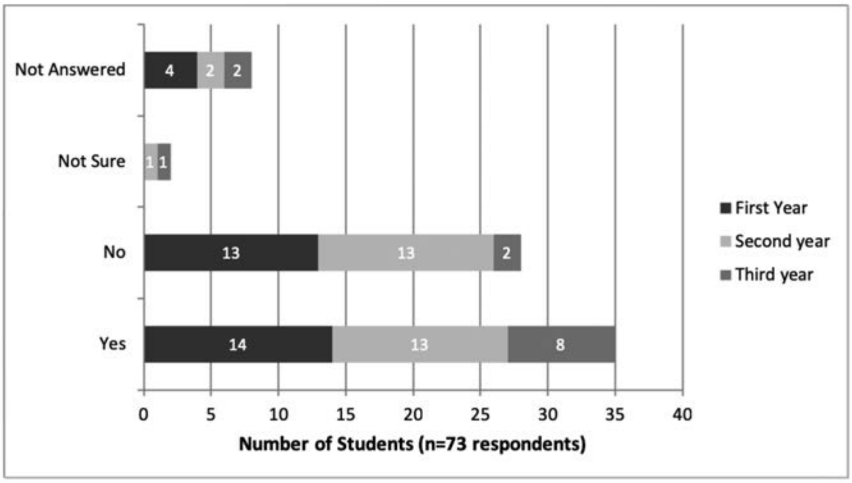


FIG. 2. Overall, do you feel you have received enough feedback on your submitted work?

mathematics degree with a view to capturing their views on the feedback they had received as part of their studies and as a means of exploring the impact of the curriculum review changes in this area. The survey adopted a similar style of questioning to that used by Robinson *et al.* (2015) in their study of student perceptions of screencast feedback. While appropriate ethical guidelines, such as those of BERA (2011) were followed in conducting the research, explicit ethical clearance for this study was not sought as the nature of the questioning and collected information was not deemed to be sensitive in nature; responses were received on a non-compulsory, anonymous and an 'opt-in' basis; and, the purpose(s) of the study were made clear to participants at the outset.

A total of 74 responses were received to the survey, representing an approximately 9% response rate: 31 were from those who were, at the time, in year 1 of their studies; 29 were in year 2; 13 were in year 3; and 1 in year 4. Given the limited response rate for year 4, where the discussion considers responses by year of study, the single year 4 respondent has been excluded.

## 4. Results

As Fig. 2 shows, there was no clear consensus upon whether students felt they had received sufficient feedback on their work, with roughly comparable numbers answering 'yes' and 'no' (48% vs. 38%). There is little difference in the responses for years 1 and 2; however, those who were in year 3 and responded were generally more positive about the level of feedback they had received although the sample size here is much smaller.

An analysis of the free-text comments provided by respondents reveals that seven (of the 35) who felt they had received sufficient feedback on their work linked this to the provision of 'model' or 'worked' solutions to the problem sheet exercises, particularly when they are provided in a prompt and easily accessible manner:

> '*Feedback was the most useful when it was returned promptly so you hadn't forgotten the material. General feedback from worksheets was very useful if it was intelligible enough. (typed rather than written).*' [S10, Yr3]

'*Detailed solutions improve understanding so that I can ensure I make as few mistakes as possible. More problems and solutions should be available!*' [S30, Yr4]

But of those 28 who said they had received insufficient feedback, eight also highlighted the value of worked solutions which indicates the expectations of students in relation to feedback clearly extend beyond the provision of worked solutions alone:

'*Model solutions were very helpful when it came to revision.*' [S26, Yr2]

'*Worked solutions on canvas enabled you to go through the solution step by step*.' [S64, Yr1]

Complementing the availability of model solutions for each assignment is generic feedback, that is written comments on the performance of all students along with the highlighting of common errors or misconceptions. Only two students referenced the value they found in this form of feedback, but overall, student comments referred to its lack of a personalized nature:

*'Some just give general conclusions same for everyone which I can recognize myself.*' [S19, Yr2]

*'Some modules gave generic feedback on mistakes that students made overall but it wasn't tailored to my work.'* [S20, Yr3]

The provision of worked solutions should be a simple task for departments since they will already exist in order to support the marking of problem sheets, although there are sometimes valid reasons for these not always being made available. What is particularly interesting to note is how students commented that they used these solutions to reflect upon their own learning; a skill critical to the effectiveness of the provided feedback (Yorke, 2003). Such solutions are generic, they do not identify where an individual student has gone wrong and the students therefore need to do this for themselves, but it does appear that the availability of worked solutions does, at least amongst some students, provide the incentive to develop their necessary skills in self-analysis and reflection; here, nine students provided specific details of how they used the worked solutions as part of their own learning process:

'*Model solutions are helpful because I can see step-by-step solutions to compare with my own, and see which parts I haven't understood properly or need to explain more clearly.*' [S7, Yr3]

'*Read through exemplar solutions and tried to understand my mistakes.*' [S49, Yr2]

'*I compared it with my own solutions and learned to implement the methods the lecturer used.*' [S66, Yr2]

Whilst there was less overall reference to 'model solutions' amongst year 1 respondents, in the instances where there were, their use again demonstrated evidence of the development of skills in self-analysis:

'*I have submitted half of the work only as sufficient feedback wasn't available, so I used to mark my work when the solutions were made available.*' [S40, Yr1]

'*I compared my answers to model solutions and used them to draft future answers.*' [S42, Yr1]

Some disciplinary surveys (for example Blair *et al*. 2013) have found that students express little concern about the amount of feedback they receive on their assignments; however, others have highlighted not only the variations in student expectations that exist between disciplines but also mismatches in staff and student expectations (Brinkworth *et al*. 2008). Here, it is clearly a concern for any department when around 40% of respondents to such a survey highlight issues with the amount of feedback they receive

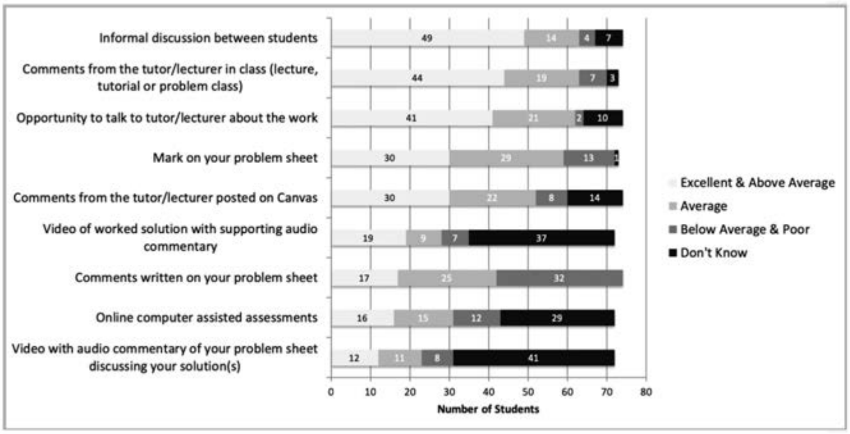


FIG. 3. Of the feedback types you said were available, please rate the quality of the feedback you received.

during their studies (Fig. 2). This may not be surprising because as Tomlinson (2014, p6) notes within the UK '*the marked increase in fees is affecting students' views of what they expect from higher education . . . they also feel it is up to them to "get as much out" of the experience as they can and maximise whatever opportunities HEIs provide*'. This does raise a fundamental question as to what, from the perspective of a learner, constitutes the point of 'I have received sufficient feedback' being reached?

In general it appears, across all years, that where students felt they did not receive sufficient feedback, this was related to the marking of their problem sheets in particular, highlighting the lack of detail in the comments as an area where it would be worth departments focusing their attention:

'*No, comments were generally not detailed enough.*' [S2, Yr3]

'*No—problem sheets are the main way to track progress and are not marked well enough.*' [S24, Yr1]

'*I feel like the problem sheets could have more feedback as it is often very generic and doesn't say where particularly I have gone wrong.*' [S58, Yr1]

Such comments were further reinforced where students were asked to rate the quality of the different types of feedback they had received. Here, 'comments written on your problem sheet' rank lowest of all possible types (Fig. 3) with 32 out of 74 respondents ranking this as either 'Below Average' or 'Poor'. Perhaps surprisingly, 'mark on your problem sheet' not only ranks relatively highly, with 30 out of 73 students ranking this as either 'Above Average' or 'Excellent' (Fig. 3), but this was also cited as the third 'best' form of feedback overall (Fig. 4).

Most interesting here is that the top two ranked forms ranked forms of feedback cited as being the 'best' by students (Fig. 4) are based around dialogue – that is discussion of their work with either their peers or staff members. Overwhelmingly, dialogue with peers was the form of feedback students reported using the most during their studies (Fig. 5) followed by the mark on their problem sheet. The link between the mark awarded and subsequent dialogue is not as surprising as it may seem as the mark can be used as the 'prompt' to stimulate individual learning and discussion with peers:

'*My mark told me generally how well certain parts of the module had gone so that when it came to revision I knew which parts to focus on more.*' [S5, Yr3]

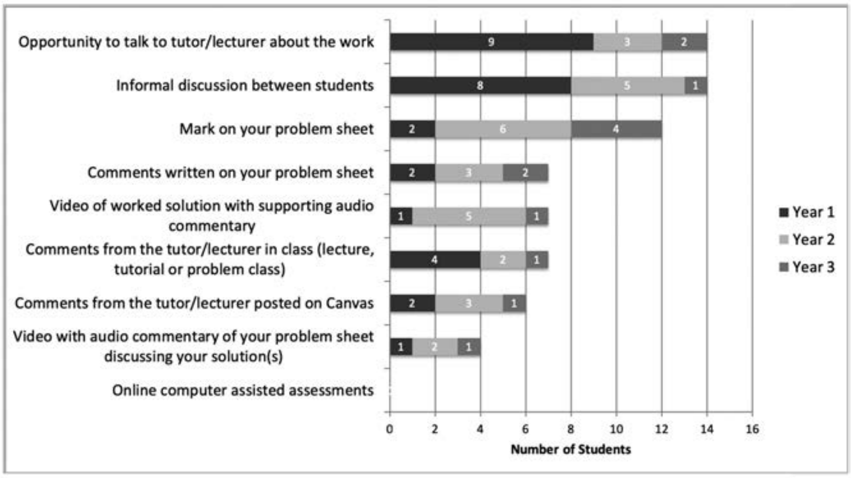


FIG. 4. What was the best feedback you received?

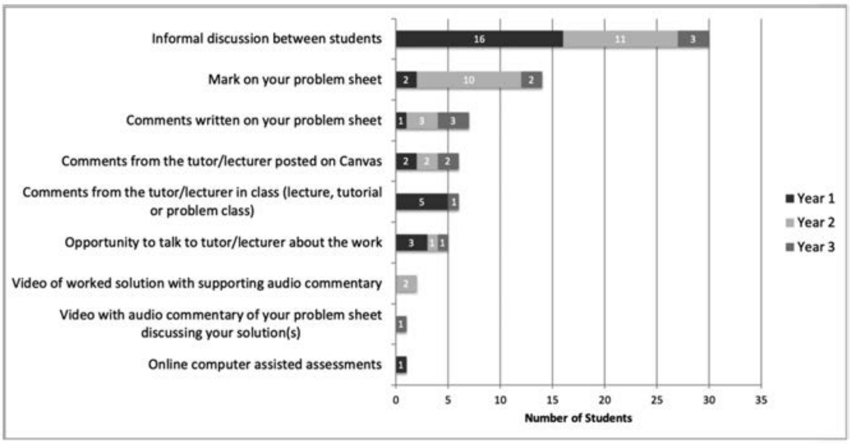


FIG. 5. Which feedback have you used the most?

> '*Discussed what marks my friends got and compare our answers. Use my marks to see which questions I need to revise more.*' [S18, Yr2]

> *'I find discussion the best as often if you haven't done too well seeing a low mark on the page can be quite negative whereas by talking to a tutor they are able to pin point where you went wrong and how to gain marks.*' [S37, Yr1]

Although dialogue is highly valued, verbal feedback from a member of staff, for example at the start of a session, also ranks highly amongst students. Such comments might be used by students as a starting point for subsequent dialogue, and comparing results from Figs 3 and 4 shows that students cite the ability to talk to staff about their work as being amongst the highest quality and 'best' feedback they have received. However, only 5 survey respondents used this as their most common form of feedback which either suggests students choose not to engage with such opportunities, or there are insufficient opportunities accessible to them. It was year 1 students who, in the main (Fig. 4), highlighted talking to staff as the most effective form of feedback; comments were directly related to the compulsory year 1 tutorial system highlighting its success as a means of increasing the effectiveness of feedback through genuine dialogue:

> '*Weekly tutorials with approachable tutors who have a clear understanding of the topics was also so useful, seeing how they and other students would attempt problems was very useful and motivated me to try harder ...*' [S37, Yr1]

> '*Discussion in tutorials as allowed you to see how you can approach different questions on the same type and how to think of questions in a different way.*' [S52, Yr1]

> '*Tutorial sessions were useful as I could get help on the areas I personally struggled.*' [S58, Yr1]

And again, explicit links were made with the mark received on a problem sheet:

> '*Because if you don't understand something then talking to a lecturer about it really makes you get to the bottom of it. Then again, I often don't know that I don't understand something unless I lose a mark in a problem sheet for it.*' [S47, Yr2]

The comments made by respondents about the feedback they received were often general in nature, but where individual modules were referenced these related to the new modules that were implemented as part of the curriculum review, Mathematical Modelling and Problem Solving (1MMPS) and Mathematics in Industry (2MI):

> '*2MI feedback was very helpful because it gave a very clear way to improve the work.*' [S15, Yr2]

> '*Feedback on MMPS group projects was helpful in that it allowed me to improve upon and become more confident in my abilities to work with others in a group and problem solving skills.*' [S42, Yr1]

> '*Feedback was good, detailed and helpful, especially in 2MI communication projects and research projects.*' [S49, Yr2]

Whilst the emphasis in both of these modules was upon group-based tasks and extensive opportunities for dialogue with peers, staff members and PGTAs, they also piloted the use of technologies to enable students to access video (including audio) based feedback of their work; 13 students made explicit positive reference to its use in these group-based modules:

> '*2MI had voice and video feedback which went through the submitted work and pointed out strengths and weaknesses within the piece.*' [S16, Yr2]

> '*Online feedback for MMPS was very detailed and helped us to improve the next projects.*' [S48, Yr1]

> '*It was useful and informative as it was very detailed and applied to our specific work in MMPS.*' [S36, Yr1]

> '*Impressive amount of personal feedback. Best way to give this sort of group feedback*.' [S74, Yr2]

When questioned as to why this video-based form of feedback was preferred, comments related to the level of detail that it could provide, and in particular its ability to highlight and explain where the student could improve upon their work:

> '*I got very detailed analysis in my video so I understood a lot better where I had gone wrong and why.*' [S14, Yr2]

'*Yes I did watch it and my team and I used it to see what we have done well and what we can improve for next time.*' [S29, Yr2]

'*It was useful to go through everything we did and highlight issues along the way.*' [S57, Yr2]

In addition to the use of video-based feedback in these new project modules, a 2-week pilot of its use with weekly problem sheet marking (for year 1 students) was undertaken, along with a pilot in a year 3 module, to see if the benefits observed in 1MMPS and 2MI might be replicated more widely amongst the student cohort. Although this pilot was limited in its scope, there were positive comments on its use although these were much smaller in number. Positive comments indicated that it was more detailed than the feedback previously provided:

'*Online feedback had a better feedback as it had more information given as to why marks were awarded or not.*' [S1, Yr3]

'*It was also used once on the problem sheets which was much better than normal marking.*' [S39, Yr1]

'*. . . it did help me clearly see the parts where I took the wrong direction with a problem or failed to realise what was being asked of me. I would take more time with my work after watching the videos as it was usually small errors that cost me marks*.' [S35, Yr3]

Overall, whilst there were clear positives relating to the use of video-based feedback for the different assignments, there were also negatives. These typically related to the length of the feedback which was most likely as a result of a deliberate attempt by the markers to provide more detailed feedback on submissions:

'*Very long, helpful but very boring.*' [S22, Yr1]

'*It often wasn't in depth enough and just pointed out what was done well and what was done not so well opposed to explaining why it was good or bad.*' [S37, Yr1]

'*. . . I think less "waffly" feedback would be good, just get straight to the point with what we need to do but this is more the person giving feedback rather than the feedback itself.*' [S70, Yr2]

'*Harder to utilise as it was in a lengthy format.*' [S71, Yr1]

Student views upon the approach of using video-based feedback for the problem sheets specifically were also mixed; the format of video-based feedback is welcomed, but they want it to be much more focused and easier for them to subsequently utilize:

'*I prefer to have feedback on paper when it comes to problem sheets so that I can make corrections straight away.*' [S21, Yr1]

In addition, whilst seven students commented specifically upon the convenience of being able to submit their work online, six students were very negative towards the approach and instead indicated they would prefer to hand-in their solutions as had been the case previously:

'*Submitting electronically is a lot of hassle. Easier to physically hand in.*' [S17, Yr3]

'*Once the files were on the computer it was easy to upload them to canvas, but it seemed like a bit of a nuisance to either have to scan in a piece of work or take a clear photo*.' [S27. Yr1]

Some of the negative issues noted above might be addressed as PGTA markers become more experienced at providing video-based feedback, and students more familiar with the submission process.

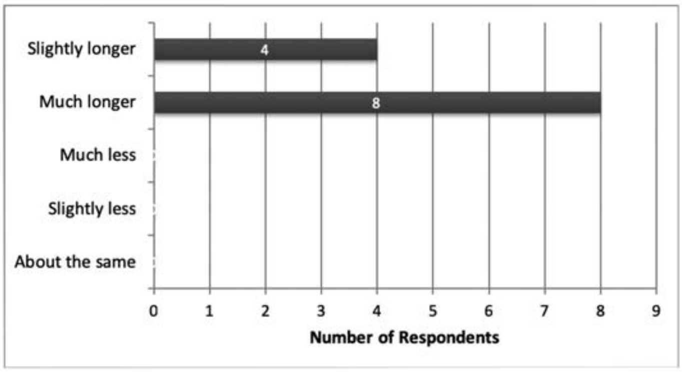


FIG. 6. Compared to the time it would take you to grade the same submissions but in a paper format, how long did it take you to complete all duties associated with marking the student work?

As such it may seem that video-based feedback on individual problem sheets has the potential for the provision of more effective feedback upon student work. However, it is important to understand its impact upon those who are providing the feedback and in particular the implications for the amount of time this takes. Within many mathematics departments, it is PGTAs who will often have a key role in the marking of problem sheets, particularly within year 1 and year 2. As this was the case here, a related short survey of 12 postgraduate teaching assistants who provided video-based feedback was undertaken to understand their views. From the responses received, it was clear that this is a much more time-intensive process than traditional paper-based methods of marking and feedback (Fig. 6):

'*Time spent recording and uploading viable recordings probably took about twice as long as writing due to the need to pre-read through work and having to additionally upload and attach the recording.*' [PGTA6]

'*Overall, even in the best case scenario - it took around twice the time to complete.*' [PGTA11]

Whilst postgraduates reported that it took longer to provide feedback in this form, only five PGTAs reported that they thought their comments were more detailed as a result. PGTAs also reported that the feedback was more difficult to provide, not only in terms of the administrative aspects associated with downloading and re-uploading submissions but because they were planning their feedback in advance rather than simply providing it in real time as was initially expected:

'*It was the same but in this case the feedback was more difficult to give (as I had to think for a moment and plan exactly what I would say).*' [PGTA4]

'*... being locked into giving feedback over an audio system can be somewhat stressful compared to writing down feedback where you can take a while to think of how to phrase a comment correctly.*' [PGTA12]

More broadly, the PGTAs noted a range of practical issues associated with marking duties using this format that may be difficult to overcome:

'*... you have to be fully concentrating on the marking and nothing else the entire time ... you can't do it on the train etc ...*' [PGTA1]

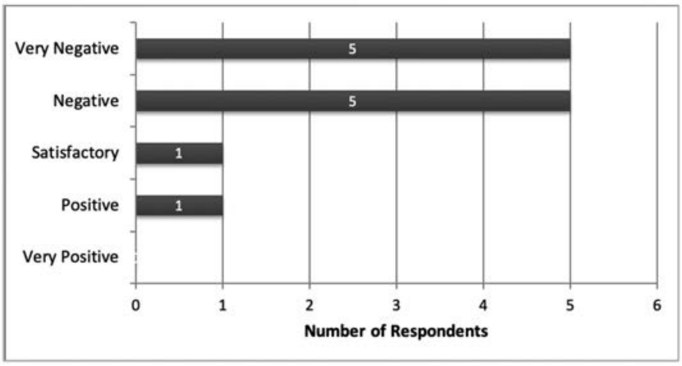


FIG. 7. How would you rate your overall experience of electronic marking?

'*. . . can't give verbal comments in an office environment, needs to be careful to not accidentally post files to the wrong people.*' [PGTA3]

The differing responses here clearly identify a challenge for departments. It is the case that some, but by no means all, students value video-based feedback, but delivering feedback in this form is not at all well liked by PGTAs (Fig. 7). In particular as one PGTA commented:

'*I find it hard to believe that the organisers of this experiment would have undertaken the work if they had to do the online grading themselves as it is so time-consuming. There is no way that the hours we were paid for covers the time wasted in the unnecessary administrative aspects of this task.*' [PGTA10]

There are cost–benefit considerations for departments in terms of the amount of marker time needed to provide such feedback, and the willingness of PGTAs to undertake it, versus the benefits offered to learners. There does, however, appear to be a balance available in how video-based feedback may be effectively used as noted by one additional PGTA involved in the trial but who sent subsequent comments via email:

*'I think the electronic marking is, in general, a good idea for certain modules (e.g. MMPS—I am not so sure if it would work for the 1st year example sheets). The type of submitted work has to be tailored to the fact that the feedback will be given electronically. For example, I think for a 10 page project it works, whereas for smaller questions broken up into parts it might not work so well.'*

This aligns with the positive comments received by students on its use within group-based projects as we have noted earlier.

## 5. Discussion and conclusions

The findings presented here offer an insight into some of the feedback practices of a large research-intensive mathematics department. They also identify some key principles upon which others might build.

When viewed from the perspective of the student, it is clear that amongst those students who responded the feedback comments currently provided on problem sheets offer limited perceived value; this is despite the considerable effort that has been put into trying to enhance this aspect. What is seen as more important to the student is receiving a mark on their work, so that they can obtain some judgement on their overall level of performance, along with a clear and obvious indication of where mathematical mistakes have occurred. This is not to suggest that students are only interested in their mark. Whilst there has been discussion about the merits of 'gradeless assessments' (see for example McMorran *et al*. 2017), as noted by Carless (2006), although students indicate they may first look at the mark awarded, they also want to improve and are genuinely interested in tutors' responses to their work. Our findings reinforce this latter aspect with the perceived value students place on dialogue with staff members about their work. Although it may seem counterintuitive, it may therefore be more effective for mathematics departments to remove written comments altogether. Doing so would also have the positive consequence of being able to speed up the return of student work, a fact which is known to be vital for the overall effectiveness of feedback (Gibbs & Simpson, 2005).

If written feedback comments on student problem sheets are removed, what feedback mechanism(s) might replace them? General comments on an assessment task made by an academic staff member, for example at the start of a formal session, are noted as being valuable by students and these might then be used as a basis for stimulating subsequent dialogue with the student(s) if the staff member actively encourages questions and comments. Complementing this approach, written generic feedback could also be provided via the VLE that summarizes the overall cohort performance on the assignment; this also forms a more efficient means for the marker of highlighting where, for example, common mistakes and misconceptions have occurred. Most significantly, however, model or worked solutions are widely regarded by students as being a vital source of feedback. Their natural existence to support the marking of problem sheets means that they can be made available to the student cohort within minutes of a submission deadline although they could readily be extended to incorporate the generic feedback on cohort performance noted above. There are, however, often quite valid reasons for not immediately uploading worked solutions, for example some students having been granted an extended deadline, but at the very least, worked solutions on formative problem sheets should be readily available when students receive their returned work.

These approaches to the provision of feedback are generic, that is they are aimed at the cohort rather than an individual, and as such transfer the emphasis on identifying the exact nature of a mathematical mistake, and its correction, from the marker to the student. For this approach to be effective, it is essential that students develop their skills in self-analysis and reflection in order to be able to interpret such generalized feedback in the context of their own self-improvement and departments clearly need to support this. This is not only an important mathematical skill, see for example the seminal work of Polya (1945) whose fourth principle of problem solving is 'looking back', but one which will also benefit their wider employability skills (Marais & Perkins, 2012). A means of achieving this is through the provision of regular sessions on how to consider and use feedback to aid learning throughout the undergraduate programme, a variant of the '*Assessment Dialogues*' proposed by Carless (2006; p220) and discussed earlier. The available evidence indicates that our embedding of such activities within the tutorial programme, through both development sessions (Collis & Sivantharajah, 2014b) and examples in practice, does appear to have been effective although there exists scope for its extension and reinforcement throughout subsequent academic years.

Whilst there is clear benefit to a department, at least in an efficiency sense, by having an emphasis upon generic feedback, it does very much remain the case that students greatly value personalized and individual opportunities for feedback. Such feedback does not necessarily have to be provided by academic staff, indeed students cite their friendship groups as being one of the best sources of feedback, and so departments can think about the provision of learning spaces where such interaction can be naturally facilitated. For example, Croft *et al*. (2008, p15) report on the pilot of a dedicated learning space for year 2 students within a mathematics department which was very effective at informally stimulating dialogue and peer learning: '*many students attend the centre in groups to work informally on coursework problems; peer support within these groups is often clearly evident ... there were also a number of discussions held amongst students regarding aspects of their courses other than assessed work ...*'. Going further, Waldock (2015) reports on the impact of a custom-designed departmental learning space for mathematics where '*student comments indicate ... increased motivation to use the space to engage with curricular and extra-curricular activity, to take part in group work and to form an active learning community*'.

Whilst departments can facilitate such opportunities for peer learning and dialogue, both formally (for example establishing PASS schemes) or informally (through the provision of student learning spaces within departments), it is possible students will either not recognize this as being feedback or identify it as feedback that is de-coupled from the departmental provision. Both are a risk to the scores of a department within the context of the NSS although departments could legitimately highlight to students the role of these activities and spaces in contributing to the feedback they receive upon their learning. It is overwhelmingly the case that students value opportunities to discuss their work, either with their peers, PGTAs or staff members. As such, time spent providing written comments might be better used in providing further opportunities for dialogue, such as an informal drop-in environment, that is not the office of a staff member, where students can attend to meet and discuss their work with either the marker or an academic member of staff. Such a finding has been reported in other studies and as such is applicable to disciplines outside of mathematics. For example, in their systematic review of the engagement of learners with feedback, Winstone *et al.* (2017, p24) identified that '*many papers emphasized a need to promote opportunities for face-to-face dialogue and peer-feedback activities*'. A further, although more challenging suggestion, involves restructuring modules such that there are significant opportunities for students to work in teams on problems and tasks as we have found to be the case with the new modules 1MMPS and 2MI.

Although we have not discussed this in any detail here, there is increasing evidence that specialist mathematics students, many of whom are actually doing rather well, are also choosing to utilize mathematics support centres as a means of engaging in personalized dialogue with an independent tutor about their learning (Grove *et al.* 2019b). This reinforces the value of the drop-in model for feedback identified above. Although not universally common, such student usage is perhaps not surprising as coupled with the increased availability of mathematics support, numerous studies have highlighted the value to students of the personalized and one-to-one support available in drop-in centres that is not available in a tutorial or lecture environment (Lawson *et al.* 2003). Indeed, the value of this personalized learning and support is found across a range of disciplines as studies have indicated that students are particularly receptive to advice received during one-to-one feedback dialogue sessions (Duncan, 2007) and view these as 'safe spaces' within which to engage in dialogue about their work (Cramp, 2011). Our next stage in the action research approach we have described involves the design and piloting of mechanisms across other modules that allow students these increased opportunities to discuss their own work with staff and PGTAs as part of their learning experience.

Whilst there will exist a role for technology in enhancing the provision of feedback in the mathematical sciences, how it is implemented requires careful consideration with the views of both students and those undertaking the marking and feedback needing to be sought. Our findings echo those of others who have implemented video-based feedback in that it is liked by a number of students (Robinson *et al.* 2015), although we have found this to be in no way universal. Although the reported negative issues might be from students averse to a change in the feedback process, there are more substantial negative views to providing video-based feedback by the PGTAs who have a key role in the marking of formative work in the mathematical sciences within many institutions. Particular concerns are noted with the amount of time providing feedback in this form takes. Some studies have indicated that providing video or screencast feedback is more time-consuming (Haxton & McGarvey, 2011); however, others have identified that it is more time efficient (Edwards *et al*. 2012), although in both cases these were disciplines outside of mathematics and involved staff members rather than PGTAs. It is likely that the speed at which an individual can provide video-based feedback will increase as they develop fluency with the technical aspects of the system; however, the PGTAs surveyed here indicated that providing the actual feedback itself was far more time-consuming through a video-based medium. Addressing this will be a challenge as there is a constraint upon just how many hours of teaching and marking support a PGTA can reasonably provide and as such thought must be given to the assessment and feedback process as a whole. Where video-based feedback does, however, offer benefits is perhaps in extended pieces of student work, such as either individual or group projects, which are less frequent and numerous in nature, or in providing (generic) feedback on the performance of an entire cohort in an assignment (Crook *et al*. 2012).

There exists a very natural desire by departments to provide 'more helpful' feedback to learners, but doing so requires a delicate balancing act between the tasks of providing sufficiently detailed and timely feedback, equipping students with the necessary skills in reflection and self-awareness to be able to use this feedback effectively for themselves, and balancing the workloads of those undertaking marking and providing feedback. Within many mathematical sciences departments, a small number of PGTAs will be tasked with providing feedback on the problem sheets of a large number of undergraduates, and as such, from the departmental perspective, this involves managing the balance between providing learners with sufficiently detailed feedback for it to be usable, but managing the time and cost implications of having PGTAs fulfil this duty. This will no doubt also be a challenge for departments and disciplines outside of mathematics.

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# Appendix

## *A.1 Survey: use of feedback in undergraduate mathematics*[1]

This survey is mainly about the work you have submitted as part of your undergraduate mathematics course, and in particular the feedback you have received upon it.

The data and information collected will not be in any way attributed to you, all responses will be completely anonymous, but your responses will contribute to an ongoing programme of educational research to explore marking and feedback within the mathematical sciences. In any findings that are published, you will be in no way identifiable as an individual.

There are 17 questions in total and this survey should not typically take you more than 15 minutes to complete. In the case of all questions, please provide any detail you can to help explain your choices.

### *A.1.1 Part 1: (initial open-ended questions).*

1. Are you a:
   [First year undergraduate; Second year undergraduate; Third year undergraduate; Fourth year undergraduate]
2. Please briefly describe all the feedback that was available to you in relation to work you have submitted <u>this</u> academic year.
3. Was any feedback particularly helpful or useful? (Please give brief reasons; what was helpful or useful to you, and why?)
4. Was any feedback particularly unhelpful?
5. Overall, do you feel you have received enough feedback on your submitted work?

### *A.1.2 Part 2: (multiple-choice questions and open-ended questions on the use of feedback).*

6. Listed below are some forms of feedback that <u>might</u> have been available to you this academic year. In each case, please indicate how much you <u>looked</u> at it/read it/used it in any way. If the feedback was not available, or you did not know that it was available, then please click that option.
   a. Mark on your problem sheet.
      [Used extensively; Used more; Used a bit; Not at all; Not available]
   b. Comments written on your problem sheet.
      [Used extensively; Used more; Used a bit; Not at all; Not available]
   c. Opportunity to talk to tutor/lecturer about the work.
      [Used extensively; Used more; Used a bit; Not at all; Not available]
   d. Video of worked solution with supporting audio commentary.
      [Used extensively; Used more; Used a bit; Not at all; Not available]

[1] Adapted from: Robinson, M., Loch, B. & Croft, A.C. (2015) ‘Student Perceptions of Screencast Feedback on Mathematics Assessment’, *Int. J. Res. Undergrad. Math. Ed.*, 1, pp363–385.

e. Video with audio commentary of your problem sheet discussing your solution(s).
[Used extensively; Used more; Used a bit; Not at all; Not available]
f. Comments from the tutor/lecturer in class (lecture, tutorial or problem class).
[Used extensively; Used more; Used a bit; Not at all; Not available]
g. Comments from the tutor/lecturer posted on Canvas.
[Used extensively; Used more; Used a bit; Not at all; Not available]
h. Informal discussion between students.
[Used extensively; Used more; Used a bit; Not at all; Not available]
i Online computer-assisted assessments.
[Used extensively; Used more; Used a bit; Not at all; Not available].

7. Of the feedback types in question 6, which of these have you used most?
[Drop down list of all 9 types from above]
8. What other means of feedback was available to you?
[Free text]
9. Of the type of feedback that you have said you have used the most in question 7. Please tell us what you did with the feedback. For example, you might have: Looked at the mark; filed it; read some comments; read all comments; compared any exemplar solutions to your own; re-read lecture notes to clear up misunderstanding; worked through questions again; talked to your tutor about difficulties; made notes when the lecturer/tutor talked about it in class; listened to what the tutor said in class; emailed the tutor to ask questions; talked to your friends or colleagues; visited the mathematics support centre or maths drop-in sessions; looked online. Or you might do something completely different not mentioned here.

*A.1.3 Part 3: (multiple-choice and open-ended questions on the quality of the feedback).*

10. For each of the feedback items which you said were available, we would like you to rate the quality of the feedback you received:

a. Mark on your problem sheet.
[Excellent; Above average; Average; Below Average; Poor; Do not know]
b. Comments written on your problem sheet.
[Excellent; Above average; Average; Below Average; Poor; Do not know]
c. Opportunity to talk to tutor/lecturer about the work.
[Excellent; Above average; Average; Below Average; Poor; Do not know]
d. Video of worked solution with supporting audio commentary.
[Excellent; Above average; Average; Below Average; Poor; Do not know]
e. Video with audio commentary of your work discussing your solution(s).
[Excellent; Above average; Average; Below Average; Poor; Do not know]
f. Comments from the tutor/lecturer in class (lecture, tutorial or problem class).
[Excellent; Above average; Average; Below Average; Poor; Do not know]
g. Comments from the tutor/lecture posted on Canvas.
[Excellent; Above average; Average; Below Average; Poor; Do not know]
h. Informal discussion between students.
[Excellent; Above average; Average; Below Average; Poor; Do not know]
i. Online computer-assisted assessments.
[Excellent; Above average; Average; Below Average; Poor; Do not know].

11. Please select the item which you think was the BEST feedback. (If you rate two or more things equally, just pick one of them. If you think most of the feedback was poor, we'd still like you to pick the one that was the least bad).

 [All 9 types of feedback listed in drop down].

12. Of the feedback item you rated most highly (or least badly!) What was it about this feedback that made it your highest rated? Why was it the best? What was good about it?

*A.1.4 Part 4: miscellany.*

We are particularly interested in any video-based feedback you have received on either your problem sheets (where appropriate) or your coursework/project submissions.

13. What did you think of the video-based feedback you may have received upon your individual (or group) work?
14. Again considering the video-based feedback on your individual or group work: Did watching it help you to understand what was required? Did it help you to understand where you went wrong? Would you do anything differently in the future (exam or future coursework) as a result of watching it?
15. How did this video-based feedback compare to your previous feedback on problem sheets?
16. Do you have any comments on the ability to submit your problem sheets and work electronically by uploading them to Canvas and on receiving your marks and feedback through Canvas?
17. Finally, what more could we do to improve the quality of the feedback you receive upon your work?

 Thank you for taking the time to complete this survey.

**Michael Grove** (m.j.grove@bham.c.uk) is Reader in STEM Education and Head of Education within the School of Mathematics at the University of Birmingham. He is a National Teaching Fellow and was Associate Director of the **sigma** Network for Mathematics and Statistics Support between 2013 and 2016.

**Chris Good** (c.good@bham.ac.uk) is Professor of Mathematics at the University of Birmingham. He is the author of over 50 research articles in general topology, set-theoretic topology, topological dynamics and mathematical education. He has a long-standing interest in teaching and was awarded the first Head of School's Excellence in Teaching Award.

# A4. The extent and uptake of mathematics support in higher education: results from the 2018 survey

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# The extent and uptake of mathematics support in higher education: results from the 2018 survey

Michael Grove[†,*], Tony Croft[‡] and Duncan Lawson[§]

[†]*School of Mathematics, University of Birmingham, Edgbaston, Birmingham B15 2TT*
[‡]*Mathematics Education Centre, Loughborough University, Loughborough LE11 3TU*
[§]**sigma**, *Coventry University, Priory St, Coventry CV1 5FB*

[*]*Corresponding author. Email:* m.j.grove@bham.ac.uk

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**In response to the well-documented challenges associated with the 'mathematics problem' in UK higher education, many institutions have implemented a programme of mathematics support. Previous surveys within the UK, undertaken in 2001, 2004 and, most recently, 2012, have shown growth in the number of institutions offering such support and indicate that the dominant form of provision is through a drop-in model. Here we report on a 2018 survey of higher education providers in England and Wales undertaken to establish not only the extent of current provision but also understand the scale of its delivery. We find that overall the proportion of higher education institutions offering mathematics support remains broadly the same, but there is considerable variation in how this support is delivered within institutions. While the drop-in model remains most common, we see evidence that the methods used to provide mathematics support are expanding and that the range of levels and subjects studied of targeted student cohorts is widening. For the first time we are able to report on the volume of use of mathematics support by students across England and Wales, and although dependent upon the institutional context, we see clear evidence of the extensive use being made of it by learners.**

## 1. Introduction and background

For almost 25 years there has existed compelling evidence of the challenges experienced by engineering, physics and mathematics undergraduates as a result of their lack of preparedness for the mathematical components of their university studies (Sutherland & Pozzi, 1995; LMS, 1995; Hawkes & Savage, 2000). While this so called 'mathematics problem' may have had its origins in the science, technology, engineering and mathematics disciplines, more recent reports have highlighted that many other students are arriving in higher education underqualified mathematically for their studies (ACME, 2011). Specific issues have now been noted in a wide range of disciplines including the biological sciences (ABPI, 2008) and the social sciences and humanities (British Academy, 2012).

One response to help mitigate the mathematical issues and challenges experienced by students in higher education has been the establishment of mathematics support (throughout we use the term ‘mathematics support’ as shorthand for the more correct ‘mathematics and statistics learning support’). As noted by Lawson *et al.* (2003) mathematics support is a ‘*facility offered to students . . . which is in addition to their regular programme of teaching, lectures, tutorials, seminars, problems classes, personal tutorials, etc.*’ It may be offered to students in a range of forms including on a drop-in or appointment basis in small groups or one-to-one (Marr & Grove, 2010). There now exists an increasing body of evidence of its effectiveness on student retention and progression (Symonds *et al.* 2007; Matthews *et al.* 2013; O’Sullivan *et al.* 2014).

The growth seen in mathematics support within UK higher education has been charted through several surveys. In 2001, Lawson *et al*. (2003) conducted the first survey to determine the extent of provision. They found that 46 out of 95 responding institutions offered some form of mathematics support provision, with the key element identified most often by respondents being the one-to-one support that is made available to students. A subsequent survey in 2004 (Perkin & Croft, 2004) showed that this had increased to 66 out of 101 responding institutions, and the most recent survey, until now, in 2012 (Perkin *et al.*, 2013) identified that 88 out of 103 responding institutions were offering some form of mathematics support. While, as its headline, the 2012 survey noted a clear increase in the number of institutions offering some form of mathematics support, it did find that within a small number provision had either ceased to exist or had been reduced in scale. The reasons for this were identified to relate to a ‘*lack of available funds or lack of strategic leadership rather than because the need for such support has disappeared’* (Perkin *et al.* 2013).

Tolley & Mackenzie (2015), however, found that by 2015, the attitudes of universities at a senior level were positive towards mathematics support and its role as part of the student learning experience. In reporting on 23 semi-structured interviews from a sample of senior management within UK universities they noted that all who were interviewed now recognized that ‘*unless they provide appropriate forms of learning support for mathematics and statistics, it is inevitable that there will be an adverse impact on their students’ satisfaction, retention, achievement and employabilit*y’. Further, they go on to conclude that ‘*mathematics support is now more visible and high-profile within HEIs and is seen as important for enhancing the student experience and aiding success*.’ Grove *et al.* (2018) reinforce these findings as they note in their study that ‘*there is evidence that the way in which mathematics support provision is ‘positioned’ within an institution is becoming increasingly strategic; in many cases there is alignment with other student-focused services.*’

Surveys exploring the extent of mathematics support provision have not only been undertaken across the UK but also within Australia and across the island of Ireland. Reporting on the results of her 2007 survey in Australia, MacGillivray (2009) notes that 32 out of Australia’s 39 universities had some form of mathematics support. In the most recent survey of mathematics support provision from the island of Ireland, Cronin *et al.* (2016) determined that mathematics support was provided in 25 of the 30 responding higher education institutions. In their 2017 survey of the extent of mathematics support, Ahmed *et al.* (2018) identified that 13 of Scotland’s 17 higher education institutions offer mathematics support. While the survey of Perkin *et al.* (2013) began to explore how mathematics support is delivered, and in doing so identified the prevalence of the drop-in model within the UK, the more recent surveys of Cronin *et al.* (2016) and Ahmed *et al.* (2018) have sought to explore national trends in how mathematics support operates within institutions with data also available on how it is delivered, who provides the support (that is, who does the tutoring) and the extent of its availability to learners.

Since 2005, there has been significant work to assist institutions across England and Wales with the establishment of their mathematics support provision and provide a national network for those working in this area. The **sigma** Network, which emerged from the **sigma** Centre for Excellence in Learning and Teaching at Loughborough and Coventry Universities with the support of the Higher Education Funding Council for England (HEFCE) (2005–2010), the National HE STEM Programme (2009–2012) and once again HEFCE (2013–2016), led, and provided a focus for, the national activities in this area. The survey of Perkin *et al.* (2013) provided an overview of the extent of mathematics support towards the end of the second period of **sigma's** funding. External funding of the **sigma** Network ended in 2016, and it has continued since then as a self-supporting community of practice. The authors therefore deemed it timely to revisit this survey to explore how the mathematics support landscape in the UK has changed since 2012. Here we report on a 2018 survey that was undertaken with the aim of not only determining the extent of current mathematics support provision but, by incorporating aspects of the sustainability review of Grove *et al.* (2018, 2019a), also offering further national insight into how it is delivered, who is involved in providing the support and for the first time, the volume of use of it made by learners.

## 2. Research methodology

The previous survey of mathematics support considered the whole of the UK (Perkin *et al.* 2013). Given the existence of recent, and comprehensive, surveys of mathematics support across the island of Ireland (Cronin *et al.* 2016) and within Scotland (Ahmed *et al.* 2018), the decision was taken not to duplicate these. As such, the survey we describe here chooses to focus upon mathematics support only within England and Wales. We discuss comparative findings with Scotland and Ireland in Section 4.

Since the last extent of provision survey in 2012 there have been changes to the higher education sector within England and Wales. Several new universities were created when a number of existing specialist institutions and university colleges were awarded university status in late 2012, and since then, a further small number of new universities, including those that have formed from private colleges, have been established. Across both England and Wales, there have also been university mergers, and as a result the Higher Education Statistics Agency now lists a total of 145 'higher education providers' based within England and Wales. Excluding private universities, those not offering undergraduate-level provision, and specialist institutions focused upon arts and medicine-based subjects, a total of 111 higher education providers were identified and invited to participate in this survey (HESA, 2018).

The survey, consisting of a total of 13 questions, was first promoted through a national mathematics support mailing list that generated a number of initial responses. Work then took place to identify, from the website of each institution, whether there existed evidence of mathematics support and if so an appropriate contact for that support. Where evidence was not found, or a response not received from the identified contact, a member of academic staff or professional services staff was selected and contacted. Finally, where this did not yield a response, senior management within the institution was approached and asked to identify a colleague who would complete the survey.

Once all data had been received, it was collated and prepared for analysis. In total 14 partially completed, duplicate or responses from outside of England and Wales were removed, leaving the 88 responses that were subsequently analysed. Cross-correlation of responses between questions was undertaken to ensure the consistency and accuracy of the data, and in a small number of instances some re-classification of the data based upon free-text responses was undertaken.

Ethical clearance for this study was granted by the University of Birmingham, and the study was conducted in line with appropriate ethical guidelines (BERA, 2014). To maintain the anonymity of those individuals who responded, and their institutions, any information that might allow them to be identified has been removed in the analysis that follows.

## 3. Results

### *3.1. Response rate and sector spread*

A total of 88 responses were received to the survey, and they are shown within Table 1 broken down by university 'mission group'. The mission groups represent groupings of universities with common interests, and as such they are helpful for classifying responses although some institutions are unaligned with any group. We choose to consider responses by these institutional groupings since they allow us to analyse the spread of mathematics support across the sector and explore whether, for example, it is less prevalent in research-intensive institutions. The common mission groups have been used: the Russell Group (representing the large research-intensive universities), University Alliance (a group formed of universities based in cities and regions), MillionPlus (an association for modern universities) and Cathedrals Group (an association for universities and university colleges with Church foundations and that are usually former teacher training institutions). Several institutions were identified as belonging to both the MillionPlus and Cathedrals Groups; here they have been categorized as belonging to the MillionPlus Group so as to avoid duplicate results in the analysis that follows.

Until 2013 there also existed the 1994 Group that represented the smaller research-intensive universities. After a number of universities left the 1994 Group to join the Russell Group in 2012, it eventually dissolved with its remaining university members becoming unaligned (i.e. members of no mission group). However, we have chosen here to adopt an additional classification of Unaligned* for these remaining 1994 Group universities since they are smaller research-intensive institutions. A number of other universities across the sector do not belong to any mission group (referred to as Unaligned in Table 1); typically such institutions could seek membership of the MillionPlus and/or University Alliance Groups but have chosen not to do so.

Considering the 88 responses received from the 111 institutions that were invited to participate in this survey, we see a response rate of 79%. While a response rate of 79% for an optional survey can be considered very high, it is nevertheless lower than the 95% and 87% achieved in the 2004 and 2012 surveys, respectively (Perkin & Croft, 2004; Perkin *et al.* 2013). However, it is difficult to compare response rates between the different surveys as the population of institutions considered differs; here, only higher education providers in England and Wales were included whereas previous surveys have considered the whole of the UK.

A key finding that is clearly seen from Table 1 is that provision of mathematics support is spread across the full range of HE mission groups in England and Wales. The vast majority of Russell Group and Unaligned* universities, typically the universities with the highest entry requirements, provide mathematics support.

TABLE 1. *Institutional responses (or otherwise) to the survey categorized by university mission group (n = 111)*

| | **Cathedrals Group** | **MillionPlus** | **Russell Group** | **University Alliance** | **Unaligned*** | **Unaligned** | **Total** |
|---|---|---|---|---|---|---|---|
| **Responded** | 5 | 11 | 18 | 14 | 11 | 29 | **88** |
| **No response** | 7 | 4 | 3 | 2 | 1 | 6 | **23** |
| **Has mathematics support** | 2 | 11 | 16 | 14 | 10 | 25 | **78** |

### 3.2. *Extent and age of mathematics support provision within institutions*

Among those institutions responding to the survey (Table 2), 89% offer some form of mathematics support. By combining the responses made to the survey with the results of our search of university webpages for evidence of mathematics support provision, we have determined that 83 of the 111 institutions (75%) we approached to participate in this survey offered mathematics support by some means (Table 3). In all but one case, a response to the survey that reported the institution concerned provided mathematics support via online resources only, the support available within institutions involves some form of direct contact between learners and tutors.

Respondents who indicated that their institution offered mathematics support were asked to provide an indication of approximately how long it had done so. The results are shown in Table 4. While three respondents indicated that their institutions used to offer mathematics support but no longer do so, four institutions have established new provision within the last year. What we observe is that within institutions mathematics support is becoming increasingly established. Almost 70% (54 out of 78) of institutions offering mathematics support have been doing so for more than 5 years, and some 53% (41 out of 78) have now been doing so for over 10 years. Given the relative sizes of the groups there appears to be no discernible differences by university mission group, which is consistent with the findings of Perkin *et al.* (2013) from the previous 2012 survey and the work of Tolley & Mackenzie (2015).

The 24 respondents who indicated that their mathematics support was established within the last 5 years were asked to articulate their reasons for doing so. Overwhelmingly (18 references) provision was established in relation to a clearly identified need for such support due to issues associated with progression, performance or student requests for such a service:

TABLE 2. *Percentage of responding institutions offering mathematics support when compared to previous (UK-wide) surveys*

| Year of survey | Number surveyed | Number responding | Number of institutions offering support | Percentage offering support (as a % of those responding) |
|---|---|---|---|---|
| 2000 (Lawson *et al.* 2001, 2002) | - | 95 | 46 | 48 |
| 2004 (Perkin & Croft, 2004) | 106 | 101 | 66 | 65 |
| 2012 (Perkin *et al.* 2013) | 119 | 103 | 88 | 85 |
| 2018 | 111 | 88 | 78 | 89 |

TABLE 3. *Whether institutions offer mathematics support (n = 111)*

| | Has mathematics support | Has never had mathematics support | Used to have mathematics support but no longer does so | Evidence of face-to-face support listed on university website | No evidence |
|---|---|---|---|---|---|
| **Responded to survey** | 78 | 7 | 3 | | |
| **Did not respond** | | | | 5 | 18 |

TABLE 4. *Length of time for which the institution has offered mathematics and/or statistics support (n = 88)*

| | <1 year | 1–3 years | 3–5 years | 5–10 years | 10+ years | Used to offer | Never offered |
|---|---|---|---|---|---|---|---|
| **Number of institutions** | 4 | 4 | 16 | 13 | 41 | 3 | 7 |

*'Students' poor progression from Year 1 to Year 2 in quantitative subjects'*

*'The Study Skills department at . . . had seen an increasing number of students who required numerical or statistical support.'*

*'A range of factors, but our primary concern currently is that BTEC[1] students tend to struggle with maths and stats elements of the curriculum . . .'*

And in several cases this need for support was recognized across the institution and supported at a senior level:

*'Institutional awareness that it was a good thing; a Faculty PVC who was prepared to fund it.'*

*'The service required a new strong central structure. In Autumn 2014 the management executive realised the need and importance to establish such structure.'*

The findings within Table 4 show the establishment of new mathematics support provision on a regular basis with eight institutions creating provision within the last 3 years. In addition, mathematics support provision was established in a further 16 institutions within the last 3 to 5 years. This period coincides with a programme of nationally funded activity through the **sigma** Network (the end of the National HE STEM programme and the subsequent period of HEFCE funding) that championed mathematics support in higher education. During the final phase of the National HE STEM programme, **sigma** assisted in the creation of new mathematics support provision at nine institutions and a further nine more during the subsequent HEFCE funding. Within the survey responses, there were five specific references that the opportunity to access support through this national network was a clear factor in their eventual establishment of mathematics support provision within the institution:

*'Growing student need for help and seed funding from **sigma**.'*

*'An initial pilot showed that there is a need for maths support, and after that the service was established with a 2-year funding support from **sigma**.'*

When responding to the question about how long the institution has offered some mathematics and statistics support provision, it is possible that some respondents indicated the length of time the current provision has been operating rather than the length of time that the institution has offered any kind of support. The authors are aware of at least one case where a respondent indicated that their provision (which is a central institutional provision) had been established within the last year although a localized departmental provision had existed for many years before that. This institution would have been included in the 2012 survey as an institution with some mathematics and statistics support provision and also included in Table 4 as an institution whose provision had been established in the last year.

### *3.3. Nature and availability of the mathematics support provision*

Institutions offering mathematics support were asked to indicate which types of support they offered and the typical number of hours per week that it is accessible to learners during term time.

As the results of Table 5 show, it is overwhelmingly the case (75 out of 78 (96%)) that the vast majority of institutions with mathematics support offer provision that includes either, or both of, one-to-

[1] BTEC (Business and Technology Education Council) qualifications are vocational qualifications taken in the final stages of pre-university education and are an alternative to the more academic A-levels.

TABLE 5. *Number of institutions offering some form of face-face mathematics and/or statistics support provision (n = 78)*

| | Number of institutions |
|---|---|
| Offering 1-1 bookable appointments only | 11 |
| Offering drop-in only | 21 |
| Offering both bookable and drop-in provision | 43 |
| Offering neither 1-1 bookable appointments or drop-in but offers some form of mathematics support | 3 |

one bookable appointments and drop-in. These are forms of support that allow students direct contact with a tutor to discuss their mathematical queries and concerns. Typically, support is provided by more than one means, and it is interesting to note that 55% (43 out of 78) of institutions with mathematics support are now offering a combination of both drop-in and one-to-one bookable appointments.

The survey also allows us to explore the extent to which both one-to-one bookable appointments and drop-in sessions are available to learners (Table 6). We see that among those institutions offering one-to-one bookable appointments and providing details 42% (21 out of 50) offer their provision for between 5 and 15 h per week, and 30% (15 out of 50) for more than 15 h per week during term time. Similar trends are seen for the drop-in provision where 32% (19 out of 60) of institutions offering this form of mathematics support and again providing details, make the provision available to learners for between 5 and 15 h per week; a further 33% (20 out of 60) make drop-in support available for more than 15 h per week.

Respondents were also asked whether they offered mathematics support via organized lectures or workshops; 68% (53 out of 78) of institutions responded that they did. Within the free-text comments a small number of references were made to examples of where mathematics support provision is now embedded within mainstream teaching:

*'Workshops are embedded in programmes and curricula.'*

*'Attending faculty lectures and providing additional maths/stats/numeracy support within the session. Providing or helping with preparation of materials, for faculty staff to deliver/provide for students.'*

*'Advice at curriculum development stage on inclusive approach to meet the needs of BTEC students. Development and delivery of subject-specific maths modules for 1st year students in Business and some Science subjects (e.g. Engineering).'*

TABLE 6. *Number of responding institutions offering bookable appointments and drop-in support (n = 78)*

| | 1-1 bookable appointments | Drop-in |
|---|---|---|
| Using and specified hours (see below) | 50 | 60 |
| Using but did not specify hours | 4 | 4 |
| Does not offer | 24 | 14 |
| Specified hours | | |
| $0 < t \leq 5$ h per week | 14 | 21 |
| $5 < t \leq 10$ h per week | 13 | 11 |
| $10 < t \leq 15$ h per week | 8 | 8 |
| $>15$ h per week | 15 | 20 |

Table 7 shows that of the responding institutions with mathematics support, only 23% (18 out of 78) were using technology to offer online real-time support to learners. Further, there is evidence that the extent of this current provision is very limited with at least 66% (12 out of 18) of institutions offering it doing so for less than 1 h per week. It was typically the case that where online real-time support was available this was an additional offering. However, in a small number of institutions there were indications that if this was taken up, it would replace some of the hours available for more traditional provision:

*'The time allocated to 1-1 bookable is the same as that allocated to Online. They are interchangeable but there is almost no take-up on the online.'*

This lack of uptake of online real-time support by learners was a theme echoed by two other respondents who provide this means of support:

*'Available on demand but not generally requested.'*

*'Up to 3 hours of 1:1 Skype appointments would be available. Not often taken up.'*

In many cases, complementing the support that involved direct interaction with learners was the provision of online resources. While these were made available by a large number of institutions, their availability was by no means universal. Of those institutions responding to the survey 23% (18 out of 78) do not provide online resources to learners. For one HEI, however, this was the only means by which they offered mathematics support with staff involved in signposting students to these resources:

[Staff] *signpost students to general maths and stats support resources but do not offer one-to-one advice.*

In addition to online provision (tutorials and resources), 28% (22 out of 78) of respondents reported that their institutions were using further alternative approaches in delivering mathematics support. These approaches all indicate ways in which mathematics support has been tailored to support particular institutional needs. From an analysis of the free-text responses to the survey, some of the common themes or approaches to emerge in this regard were facilitating group or peer support activities (5 references), email and telephone support (5 references), diagnostic testing (3 references) and supporting widening access or those with mathematics anxiety (3 references). The following are specific examples to highlight the range and flexibility of the provision offered:

*'Drop-in workshops for first year maths students run by older maths undergraduates; Group study skills supported for referred mathematics students; Group or 1:1 support for entrants with BTEC or Access qualifications to some subjects.'*

TABLE 7. *Number of responding institutions offering online support (n = 78)*

| | **Online (real-time) tutorials** | **Online resources** |
|---|---|---|
| Using and specified hours (see below) | 15 | |
| Using but did not specify hours | 3 | 60 |
| Does not offer | 60 | 18 |
| Specified hours | | |
| $0 < t \leq 1$ h per week | 12 | |
| $1 < t \leq 3$ h per week | 2 | |
| $>3$ h per week | 1 | |

*'Diagnostic testing in collaboration with academics in different departments to identify struggling students and put in place collaborative and appropriate subject-specific support.'*

*'There are some telephone statistics appointments for distance learners as and when needed.'*

*'Host a monthly widening participation interactive seminar series.'*

### 3.4. *Permitted users of mathematics support*

As we noted earlier, the 'mathematics problem', to which the predominant response has been the establishment of mathematics support, had its origins in the STEM disciplines. However, it is now clear that many other groups of students, including mathematics specialists, require support at the transition to university and in many cases throughout their studies. There is also evidence that postgraduates and staff themselves are in need of support and are benefitting from mathematics support. The groups to which mathematics support is made available within institutions were explored within the survey. As Table 8 demonstrates, while it is the case that in just over 80% (64 out of 78) of institutions mathematics support is noted as being available to all undergraduates, in some institutions there are restrictions placed upon the undergraduate cohorts that can access it. Details of these restrictions were not provided by many respondents who indicated that they existed, but in one case this was noted to be specialist (that is single or joint honours) mathematics students:

*'"Some undergraduates" was highlighted because UGs actually studying Maths and Stats can't use* [the mathematics support service]. *It's for UGs from all other Schools.'*

In almost 75% (58 out of 78) of institutions providing mathematics support, the provision is available to postgraduate taught students, that is those studying Level 7 qualifications and above including master's degrees and postgraduate certificates. In almost 60% (46 out of 78), it is also available to postgraduate research students. Some 32% (25 out of 78) of responding institutions also make their mathematics support available to members of staff from within the institution.

Seven respondents to the survey indicated their provision was available to other groups. These responses again provided examples of how mathematics support has been tailored by institutions to meet their specific needs and circumstances. While one referenced their alumni, three respondents specifically referenced students studying within associated partners of the institution and three referenced potential applicants to courses within their institutions:

*'We do see other staff and students from our Associate College Partners...'*

*'Applicants to PCGE courses for their numeracy tests'*

*'Others include: Students from the International College in* [the region]*, that study in programmes linked to the University.* [Also] *Distance and work-based learners.'*

TABLE 8. *Who mathematics support is available to within responding institutions (n = 78)*

| | All Undergraduates | Some Undergraduates | Postgraduate Research students | Postgraduate Taught students | Staff | Other |
|---|---|---|---|---|---|---|
| **Number of institutions** | 64 | 14 | 46 | 58 | 25 | 7 |

### 3.5. *Who delivers mathematics support?*

Grove *et al.* (2019a) explored who was involved in the delivery of mathematics support on a day-to-day basis within institutions. Here we choose to extend their approach to not only identify that a range of different groups of individuals are involved in delivering mathematics support within institutions (Table 9) but also to ascertain details of the number of individuals (headcount) involved in the delivery of mathematics support to students within institutions (Table 10).

It is the case within the responding institutions that full-time and part-time staff, appointed with a specific remit within their roles of providing mathematics support, are responsible for the delivery of provision in 63% (49 out of 78) of institutions. Although not shown in Table 10, the Russell Group differs from the rest of the sector here. Only 38% (6 out of 16) of Russell Group institutions report having such specialist staff compared to 69% (43 out of 62) of all other institutions. Among the 49 institutions who reported they had specific full-time or part-time staff employed to deliver mathematics support, in 16 institutions (33%) these individuals were identified to be the sole providers of the provision; further, in six of these institutions (12%) there was a single member of staff delivering the entire mathematics support provision; we will return to this point during the discussion. This is in contrast to institutions where academic staff were identified to be involved in the delivery of mathematics support; in such institutions, only 12% (3 out of 26) used academic staff as the sole providers of mathematics support. While hourly paid or sessional staff have a role in the provision of mathematics support, the proportions here are lower with only around 35% of institutions making use of such individuals.

Table 11 shows the involvement of students, both postgraduate and undergraduate, in the delivery of mathematics support. Since the figures from Russell Group institutions are quite different from other institutions, these are shown separately.

Postgraduates were used to provide mathematics support in 42% (33 out of 78) of all responding institutions (Table 9). Within the Russell Group institutions, much more use is made of postgraduate students (or postgraduate teaching assistants as they are sometimes called) to deliver mathematics support. Indeed, all but one Russell Group institution indicated that they use them as tutors; however, this particular centre had been open for less than a year and so is likely to have still been in its set-up or development phase. In fact, the Russell Group accounts for 45% (15 out of 33) of all institutions using

TABLE 9. *How mathematics support is provided within responding institutions (n = 78). Note that this does not sum to 100% due to many institutions using several different types of staff*

| | **Percentage of responding institutions** |
|---|---|
| Full-time or part-time mathematics and/or statistics support staff | 63 |
| Postgraduate students or PGTAs | 42 |
| Hourly paid or sessional staff | 35 |
| Academic staff from departments | 33 |
| Undergraduate students | 26 |

TABLE 10. *Number of individual staff (headcount) involved in delivering mathematics support to learners (n = 78). Note that no response is different from a response of 0*

| **Number of individuals (headcount)** | **0** | **1** | **2–3** | **4–5** | **6–10** | **11+** | **Total responding** | **No response** |
|---|---|---|---|---|---|---|---|---|
| Full-time or part-time mathematics and/or statistics support staff | 8 | 23 | 22 | 3 | 1 | 0 | 57 | 21 |
| Hourly paid or sessional staff | 15 | 11 | 9 | 4 | 2 | 1 | 42 | 36 |
| Academic staff from departments | 15 | 10 | 3 | 4 | 4 | 5 | 41 | 37 |

TABLE 11. *Number of individual students (headcount) involved in delivering mathematics support to learners (n = 78). Note that no response is different from a response of 0*

| Number of individuals (headcount) | 0 | 1–2 | 3–10 | 11–20 | 21+ | Total responding | No response |
|---|---|---|---|---|---|---|---|
| Postgraduate students (Russell Group universities) | 0 | 2 | 7 | 4 | 2 | 15 | 1 |
| Postgraduate students (other universities) | 17 | 8 | 9 | 0 | 1 | 35 | 27 |
| | **0** | **1–5** | **6–10** | **10–25** | **26+** | | |
| Undergraduate students (Russell Group universities) | 1 | 2 | 2 | 1 | 1 | 7 | 9 |
| Undergraduate students (other universities) | 16 | 10 | 2 | 1 | 1 | 30 | 32 |

postgraduate students for mathematics support despite Russell Group institutions forming just over 20% of the institutional responses to the survey. In total there were seven institutions, six of whom who were in the Russell Group, where mathematics support was provided solely by postgraduate teaching assistants.

While 26% (20 out of 78) of institutions reported using undergraduate students as tutors, including one institution which was solely reliant upon them, generally the overall number of undergraduate students involved in tutoring within any one institution is small.

### 3.6. *Extent of engagement with mathematics support*

Respondents were asked to indicate the approximate number of engagements with mathematics support by students within their institutions over an academic year. While some figures were precise, others were clearly estimated. The results are summarized in Table 12. Of those responding with data, 41% (28 out of 68) reported that there were in excess of 1,000 student engagements with their service over an academic year, and 56% (38 out of 68) reported more than 500 engagements. It is worth noting that two of the institutions who reported fewer than 100 student engagements had been established for less than 12 months and so were unlikely to have had data spanning a full academic year available. Considering all 68 institutions who provided data, the total number of reported student engagements with mathematics support across England and Wales totals just over 85,000 in an academic year, with the largest centre alone reporting some 15,000 engagements with their service by learners.

When respondents were asked to indicate the number of individual students engaging with mathematics support at least once over an academic year, the data provided indicated a greater level of uncertainty. In a number of cases, figures were estimated, and several respondents noted that this level of data was either not collected, or if it was, it would take significant time to analyse.

Nevertheless, while the results in Table 13 should be interpreted with a degree of caution, they do offer interesting insight into the engagement by individual students with mathematics support.

Among those institutions who returned data, 42% (27 out of 64) reported engagement by a minimum of 350 different students with mathematics support in an academic year; 67% (43 out of 64) reported

TABLE 12. *Number of engagements (N) with mathematics support over a typical academic year (n = 78)*

| | No data provided | $1 \leq N < 100$ | $100 \leq N < 250$ | $250 \leq N < 500$ | $500 \leq N < 1000$ | $1000 \leq N < 2000$ | $2000 \leq N < 3500$ | $N > 3500$ |
|---|---|---|---|---|---|---|---|---|
| **Number of institutions** | 10 | 7 | 7 | 16 | 10 | 15 | 10 | 3 |

Table 13. *Number of individual students (X) who engage at least once with mathematics support over a typical academic year (n = 78)*

| | No data provided | $1 \le X < 100$ | $100 \le X < 200$ | $200 \le X < 350$ | $350 \le X < 500$ | $500 \le X < 750$ | $750 \le X < 1250$ | $X > 1250$ |
|---|---|---|---|---|---|---|---|---|
| **Number of institutions** | 14 | 10 | 11 | 16 | 8 | 5 | 7 | 7 |

engagement by at least 200 students a year. There were extensive levels of student engagement with mathematics support within a number of institutions; 22% (14 out of 64) reported over 750 students individual students engaged with their service, and 11% (7 out of 64) reported engagement from over 1250 distinct students. While it is important to remember the uncertainty noted by respondents in their reported figures, considering all 64 institutions across England and Wales who provided data, the total number of individual students reported as engaging with mathematics support at least once during an academic year totals just under 34,000.

## 4. International comparisons

With surveys exploring mathematics support within Ireland and Scotland having been recently completed, we now look to collate the results from these in order to provide a comprehensive 'snapshot' of the extent of mathematics support within the UK and Ireland. Given there exist differences in the nature of the questions within the three surveys, we limit our comparisons to the aspects where there is direct equivalence in questioning. The results of this are shown in Table 14.

When seeking to make comparisons between the results from the different surveys it should be remembered that in England and Wales, contact was made with over double the number of institutions of the Scotland and Ireland surveys combined. Nevertheless, the data are broadly similar in terms of the proportions of institutions (contacted or otherwise) with mathematics support. In all cases, drop-in provision is the most common means of support, but fewer institutions offer bookable one-to-one appointments in Ireland. While the proportions are slightly lower in Scotland, a comparable number of institutions within England and Wales and Ireland are offering support through workshops. This further reinforces how the delivery of mathematics support is extending beyond the traditional model of one-to-one appointments and drop-in within institutions.

As in Table 7 'Online Resources' in Table 14 refers to items like links to websites or the use of online virtual learning environments within mathematics support and does not include online real-time tutorials. No data is available in relation to institutions using technology to deliver online real-time tutorials within Scotland. Only one institution in Ireland reported using Skype appointments (Cronin *et al.* 2016), whereas Table 7 shows that 23% of responding institutions across England and Wales report offering these. However, as noted earlier, there is generally limited student uptake of this provision.

The surveys collectively show a large proportion of institutions are using substantive staff (by which we mean full-time or part-time mathematics and or statistics support staff and academic staff from departments; see Table 9). Here, the results from England and Wales include both those with specifically appointed roles within mathematics support and academic staff from departments; this is to ensure consistency in the presentation of results with those from Scotland (Ahmed *et al.* 2018; Table 6) and Ireland (Cronin *et al.* 2016; Table 6). Again in all three surveys there is evidence of the role of postgraduate students as tutors within mathematics support in many institutions. Significantly, within

TABLE 14. *Comparison of most recent surveys of mathematics support provision in England and Wales, Ireland and Scotland. In all cases percentages are the percentage of institutions*

| | | England and Wales | Ireland | Scotland | Aggregated: UK and Ireland |
|---|---|---|---|---|---|
| Date undertaken | | 2018 | 2015 | 2016 | — |
| Source reference | | — | Cronin *et al.* (2016) | Ahmed *et al.* (2018) | — |
| Percentage of contacted institutions responding | | 79% (88/111) | 97% (30/31) | 89% (17/19) | **84% (135/161)** |
| Percentage of all contacted institutions with mathematics support | | 75% (83/111) | 81% (25/31) | 68% (13/19) | **75% (121/161)** |
| Percentage of all responding institutions with mathematics support | | 89% (78/88) | 83% (25/30) | 76% (13/17) | **86% (116/135)** |
| Type of mathematics support provision | Drop-in | 82% (64/78) | 88% (22/25) | 77% (10/13) | **83% (96/116)** |
| | (Bookable) one-to-one appointments | 69% (54/78) | 44% (11/25) | 77% (10/13) | **65% (75/116)** |
| | Workshops | 68% (53/78) | 64% (16/25) | 54% (7/13) | **66% (76/116)** |
| | Online resources | 77% (60/78) | 48% (12/25) | 62% (8/13) | **69% (80/116)** |
| Tutors within mathematics support | Full-time or part-time staff | 81% (63/78) | 72% (18/25) | 69% (9/13) | **78% (90/116)** |
| | Postgraduate students | 42% (33/78) | 48% (12/25) | 62% (8/13) | **46% (53/116)** |
| | Undergraduate students | 26% (20/78) | 36% (9/25) | 8% (1/13) | **26% (30/116)** |

England and Wales and across Ireland, undergraduates also have a role as tutors within a number of institutions; although figures are shown for Scotland, it is important to note that this survey did not explicitly seek details of undergraduates working as tutors in mathematics support and so the reported figure is likely to be an underestimate.

## 5. Discussion and conclusions

The survey described here, although focusing for the first time upon mathematics support within only England and Wales, offers greater insight into how this support operates within the higher education sector than the previous surveys in 2000, 2004 and 2012. With a response rate of 79% we have been able to obtain a comprehensive overview of mathematics support within higher education providers and explore how it is delivered, who works as its tutors and its longevity. Perhaps most significantly for the first time we have been able to identify, at a national level, the extent to which students engage with mathematics support within their institutions.

As a headline, we see evidence of mathematics support provision within at least 75% of the institutions approached to participate in this survey of mathematics support provision. Among those institutions responding directly to the survey, 89% reported offering some form of mathematics support. It is important to note the differences in the survey populations between the two surveys; however, our findings for the extent of mathematics support provision are broadly similar to those from the 2012 survey of Perkin *et al.* (2013). While three institutions reported that they used to offer mathematics support, but no longer do so, four institutions have established such provision in the last 12 months. As Table 3 demonstrates, significant growth in mathematics support provision was seen between 2000 and 2004 and again between 2004 and 2012; growth at this rate is impossible to sustain given the high proportion of institutions now offering some form of provision. There are now relatively few institutions not offering mathematics support, and most (if not all of these) will have deemed that there is not sufficient need in their institution for such support.

There also exists evidence of the increasing longevity of mathematics support within institutions. Almost 70% of responding institutions have provision that has been established for at least 5 years, and 53% have provision that has been established for more than 10 years. Coupled with this longevity, there is evidence that how mathematics support is being provided, and to whom, has changed. While the drop-in model remains the most common method of support, this is being increasingly combined with one-to-one appointments with 55% of institutions reporting this to be the case. Both forms of support allow students to interact face-to-face with, as Lawson *et al.* (2003) note, a tutor '*who is willing to take time to explain things to them*', and it is this aspect that is known to be particularly valued by learners. While not widespread, with only some 23% of responding institutions reporting doing so, technology is now being utilized to deliver mathematics support through online real-time tutorials. Uptake of this form of support among students does however appear to be low, and this is a trend that has also been noted by others. For example, when Rice & O'Hare (2012) piloted online one-to-one tutorials, no students accessed them; however, at the same time they did observe an increase in the uptake of face-to-face support. On the other hand, a pilot of a shared online statistics advisory service (Owen *et al.* 2011) reported a good level of usage by students from institutions that did not provide their own statistics support. Taken together, these findings perhaps indicate that students highly value one-to-one support and would prefer it to be in person, but if in person support is not available then they will use online one-to-one support.

Organized lectures and workshops are being increasingly used as a means of providing mathematics support; here, 68% of institutions responding to the survey indicated that they offered this form of provision. In addition, a number of examples were cited by respondents to the survey of how their institutions were working with those involved in more mainstream teaching activities to embed ideas and approaches from mathematics support to enhance delivery.

We have previously noted the definition of mathematics support given by Lawson *et al.* (2003) as a '*facility offered to students . . . which is* ***in addition*** [our emphasis] *to their regular programme of teaching* . . .'. These new embedded forms of mathematics support challenge this definition in as much as they may be regarded as part of the '*regular programme of teaching*' and so in one sense are not additional. These forms of support have the potential to reach more students since they do not rely on students opting in, but their nature is such that they cannot deliver some of the well-documented benefits of traditional mathematics support (Solomon *et al.* 2010).

In addition, a number of respondents reported that their institutions delivered mathematics support in new ways, extending beyond drop-in, one-to-one appointments, organized lectures and workshops and online tutorials and resources. These alternative modes of delivery demonstrate the ability of mathematics support to be tailored to better meet the needs of learners and the priorities of institutions.

More broadly, there has been an expansion in terms of the student cohorts targeted by mathematics support. While it remains universally accessible to undergraduate students, albeit with some restrictions in 18% of institutions, it is now widely available to postgraduate students, and in 32% of institutions, it is also available to staff members. In some institutions, there are restrictions upon whether specialist mathematics students can access mathematics support; this in itself is an interesting development as it is known that within some institutions, where such students are able to access mathematics support, they do so in large numbers (Grove *et al.* 2019b). The observed increased availability of mathematics support to postgraduate students is also consistent with the findings of Tolley & Mackenzie (2015) who not only reported the concerns of senior management in relation to the statistical skills of postgraduate students but also how institutions were using mathematics support as a response to this issue. More significantly, the evidence of mathematics support being available to staff members may indicate a response to a finding of the British Academy (2012) that linked the poor mathematical skills of undergraduates with '*the dearth of academic staff able to teach quantitative metho*ds'; staff may be using the service to enhance their own mathematical knowledge and skills. Although smaller in number, examples were also noted by respondents of how their institutions are making mathematics support available to learners within partner institutions, perhaps as a means of encouraging progression to higher education or as a potential recruitment mechanism.

This broadening in who can access mathematics support does, however, pose real challenges for those who deliver it. With a more varied user base, queries can extend well beyond the level of those asked by engineering students making the transition to university study, which is where mathematics support had its origins (Croft, 2000). Postgraduate students have an important role in supporting its delivery in some 42% of institutions. In fact, in 9% of institutions responding to the survey, postgraduate students were solely responsible for the provision of mathematics support as tutors, and in nearly 40% of Russell Group institutions this was the case. There has been much work across the sector to support postgraduate students involved in mathematics support (see for example Croft & Grove, 2016), but there has been little focus upon undergraduate students who work as tutors in mathematics support. It may have been previously assumed that they had only a limited involvement, if any; however, as we have found here, it is now the case that they do have a significant role as just over a quarter of responding institutions reported that they used undergraduates as tutors.

Working in mathematics support is known to be quite different from other forms of university teaching (Croft & Grove, 2016), and so in addition to ensuring that all those working in this area receive some form of introductory training, there is real value in those involved in its delivery coming together periodically to share experiences and discuss issues and challenges encountered. The experience of such a community of tutors has recently been explored within one institution (Grove & Croft, 2019). While some institutions have a number of individuals involved in the provision of mathematics support, and as such can facilitate this interaction internally, in others, the provision of mathematics support is a more isolated endeavour. In six of the responding institutions, a single member of full-time or part-time mathematics support staff was the sole deliverer of the provision. As such, how these potentially isolated individuals can continue to be supported and engaged as part of a national network or community remains an important issue for consideration.

The widening seen in mathematics support is occurring at the same time as it is becoming increasingly embedded within the core provision and practices of institutions. It is not only being delivered in different ways, but its availability within institutions is becoming extensive. Just over 55% of institutions responding to the survey are offering either drop-in or one-to-one appointments for more than 10 hours per week, and 38% are offering either of them for more than 15 hours per week, during term time. Tolley & Mackenzie (2015) identified, through their interviews with university senior management, that institutions are increasingly putting in place measures to address the issues they encounter associated with the mathematics problem. Further, Grove *et al.* (2018) identified that there exists increasing alignment of mathematics support with other student-focused services within institutions and in their follow-on work (Grove *et al.* 2019a) that many institutions now have dedicated staff roles associated with the provision of mathematics support.

Perhaps the most compelling evidence of mathematics support becoming embedded within institutions is the use of it that is now made by learners. While it was apparent that there exist challenges around the collection and analysis of data on student engagement with mathematics support, a fact noted previously by Matthews *et al.* (2013) in their review of the literature, it is nevertheless the case that the data do show the extensive engagement made by students across the higher education sector with mathematics support. Among those responding institutions who reported student visits across an academic year, 56% saw more than 500 engagements and 41% more than 1,000, with one institution reporting more than 15,000 engagements. Clearly such results must be interpreted within the context of the institution itself, for example its size, who the support is available to, mode of delivery and the number of hours for which it is available. Across the sector as a whole, a total of around 85,000 engagements with mathematics support in an academic year were reported.

While such headline figures demonstrate extensive student engagement, they cannot be used as a measure of the quality of mathematics support or the ultimate benefit that it offers to learners. As Lawson *et al.* (2003) have noted, students are known to greatly value the individual interactions with a tutor that mathematics support offers. As such an institution reporting a smaller number of these face-to-face engagements may see a far greater impact on the student experience than one reporting a figure many times this number but where the mathematics support is delivered by entirely different means.

From the results of this survey, we have been able to identify a number of areas where further research would offer benefits to the higher education sector:

1. We have presented evidence on how the delivery of mathematics support by institutions has expanded. While there exist evaluations of drop-in support, or similar (see for example O'Sullivan *et al.* 2014 for a comprehensive evaluation), more work is needed to understand the impact of mathematics support in its new and different forms. Related to this is the need for research to explore how these different forms of support are delivered and, in particular, how well they guide students towards becoming more independent learners.
2. In an increasingly technological society, the limited engagement by students with online real-time support is interesting and worthy of further study. It may be that this lack of uptake further reinforces the great value that students are known to place upon the person-to-person contact of mathematics support (Lawson *et al.* 2003). Equally, it may be that even though such opportunities for support are not utilized by learners, they nevertheless have a wider role in raising awareness of the mathematics support provision that is available within an institution.
3. It is now the case that a wide range of different individuals (for example specialist staff, academic staff, postgraduate students, undergraduates, etc.) are working as tutors in mathematics support across the sector. This raises the valid question of who are the best individuals to tutor the wide range of users who now access mathematics support within institutions.
4. Mathematics support is now widely available to a range of different individuals, but, at the same time at least within a small number of institutions, restrictions are placed upon the undergraduate cohorts who can access it. Understanding just who is using the available provision, how they are using it to aid their learning and whether there are differences between these groups could have implications for how mathematics support operates more widely. Significantly, it should also not be forgotten that while we have shown extensive engagement by students with mathematics support, there still exist many students who choose not to avail themselves of the support when they would most likely benefit from doing so. As such, understanding this lack of engagement remains very important.

Finally, by collating the most recent results of the surveys of mathematics support across England and Wales, Ireland and Scotland, we are able to present the most comprehensive overview of the extent of mathematics support undertaken to date. Considering 160 higher education providers, of which 135 responded to the survey requests, we see 75% of contacted institutions offering mathematics support, and 86% of responding institutions offering mathematics support. While intuitively we expect the 'true' overall figure to be closer to 75% than 86%, since institutions are more likely to respond to survey requests if they have provision than if they do not, regardless it shows that mathematics support is extensively available within higher education providers across the UK and Ireland. Further, there exists no evidence in any survey (Ahmed *et al.* 2018; Cronin *et al.* 2016) that the provision of mathematics support within institutions is declining. As such mathematics support is now a widely available, accessible and extensively used service within institutions to support students with the challenges that they may face with the mathematical components of their higher education studies.

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**Michael Grove** (m.j.grove@bham.c.uk) is a Reader in STEM Education and Head of Education within the School of Mathematics at the University of Birmingham. He is a National Teaching Fellow and was associate director of the **sigma** Network for Mathematics and Statistics Support between 2013 and 2016.

**Tony Croft** (a.c.croft@lboro.ac.uk) is Emeritus Professor of Mathematics Education at Loughborough University and has developed mathematics support there for many years. He was a founding director of the **sigma** Centre for Excellence in University-wide Mathematics and Statistics Support. He was also a director of mathcentre, the UK's virtual mathematics support centre, and was awarded a National Teaching Fellowship in 2008. He was jointly awarded the IMA Gold Medal 2016 for his outstanding contribution to mathematics education.

**Duncan Lawson** (duncan.lawson@coventry.ac.uk): after 5 years (2013-2018) as pro-vice-chancellor (Formative Education) at Newman University, Duncan returned to Coventry University where he had previously worked in mathematics support for over 20 years, having been a founding director of the **sigma** Centre for Excellence in University-wide mathematics and statistics support. He was awarded a National Teaching Fellowship in 2005 and was also jointly awarded the IMA Gold Medal 2016 for his outstanding contribution to mathematics education.

# A5. Specialist and more-able mathematics students: understanding their engagement with mathematics support

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# Specialist and more-able mathematics students: understanding their engagement with mathematics support

Michael Grove[1], Sophie Guiry[2] and Tony Croft[3]

[1] *School of Mathematics, University of Birmingham, Birmingham, UK*

*Corresponding author: m.j.grove@bham.ac.uk; +44121 414 8519.*

*ORCID: 0000-0002-3150-125X*

[2] *School of Mathematics, University of Birmingham, Birmingham, UK*

[3] *Mathematics Education Centre, Loughborough University, Loughborough, UK*

*ORCID: 0000-0002-7980-9579*

Along with a growing body of evidence of the challenges experienced by specialist and more-able mathematics students during their undergraduate studies, there now exists evidence that these students are increasingly accessing mathematics support centres as a means of enhancing their mathematical learning experience. Here we report on a survey of 47 specialist mathematics students, studying within the mathematics department of a large, UK research-intensive university. Our findings show that whilst such students have high levels of engagement with core teaching components, additional, and optional, opportunities for personalised support and dialogue provided by the mathematics department to support their studies are less well used and valued. Friends provide an important source of additional support along with visits to the mathematics support centre. Our data show that users of mathematics support from later years are not necessarily returners, but instead are new to the centre. Whilst many students use the centre only occasionally and as the need arises, there is evidence that others are more regular users and are using the centre as a core part of their mathematical learning experience. The reasons given for their usage are linked to the convenient availability of support, its personalised nature with friendly tutors of a similar-age and subject profile, the ability to use the centre as a group study space to work with friends, and as an opportunity to engage in dialogue about their mathematical learning.

Keywords: mathematics support, peer support, postgraduate tutors, dialogue.

## 1. Introduction and background

Well-documented challenges exist [1,2] relating to the learning of mathematics by students beginning their undergraduate studies within the UK. Whilst much of the work exploring the issues has focused upon the transition between school and university and in disciplines such as engineering [3] and physics [4], there is an increasing body of literature exploring the learning experience of what we call the *specialist mathematics student*; that is the student who chooses to come to university to study single or joint honours undergraduate mathematics programmes. Croft and Grove [5] provide an overview of the literature in this area and in doing so note concerns in relation to staff-student relationships, the quality of teaching, pedagogic practices and students becoming demotivated as their studies progress. Mathematics support [6], and in particular the mathematics support centre (described fully below), may have had its origins as a means of assisting students who were struggling with their learning of mathematics in engineering, however there is now evidence that specialist, and indeed more-able, mathematics students are also taking advantage of the opportunities that mathematics support offers [7,8]. The work we describe here was undertaken in response to the observed usage of the mathematics support centre in a research-intensive university by the specialist and more-able mathematics student. Our motivation was to answer the following research questions: 1) to what extent is use made of the mathematics support centre by specialist mathematics students? And, 2) what are their reasons or motivations for the usage patterns observed? We begin by considering the context within which this work was situated.

### *1.1. The undergraduate learning experience of specialist mathematics students*

As Solomon [9] notes, many students are motivated to study mathematics at university because they are successful at the subject and find it easy whilst at school or college. They begin their university studies with a positive attitude towards the subject, and whilst for some this positivity will remain throughout, for others their attitudes towards the subject change as their studies progress. Daskalogianni and Simpson [10] refer to this change in student attitudes as '*cooling-off*'. They note that when these 'cooling-off' students begin their university studies the teaching and learning environment they encounter is not only different from that experienced at school or college but that it is also different '*from the one they know how to function in successfull*y'. As a consequence for these cooling-off students, the '*experienced mismatch between their beliefs about the nature of mathematics and its rigorous university character soon makes them lose their interest in mathematics and develop a negative attitude towards it*' [10].

In their three-year project examining the progress and changing attitudes of a cohort of single honours mathematics students in two research-intensive universities, Brown et al. [11] identify that one of the factors influencing students' attitudes towards mathematics was success at the subject. They found that amongst those students whose attainment was average and below '*the problems of coping with the work were accompanied by a growing disillusionment with mathematics.*' In general, although as they note not in all cases, they found this to be coupled with a decline in the students' enjoyment of mathematics over time, and identified that this was linked to perceptions of success in the subject: '*When some no longer perceived themselves to be particularly successful, there was little to motivate them to continue studying except a need to maintain self-esteem and gain credentials*'.

Goulding et al. [12] cite evidence from students of the challenge in maintaining an enjoyment of mathematics when they experience difficulties in understanding it, but go on to identify that for '*those students who chose to comment about the university teaching they had experienced, most were very critical of the teachers and the teaching methods, particularly lectures*.' Williams [13] found that students identified lectures at university as intimidating places and were not sure how to learn within them. Brown et al. [11] identify a clear link between the lecture and student perceptions of their success when studying mathematics: '*Students who found they could not follow many of the later lectures in a series and could not do much of the work set, were in no doubt about their lack of success*.' One of the issues most commonly cited by students in relation to the lecture is its lack of interactivity, with Williams [14] going as far as noting that in his research study the lecture '*was observed habitually to become a monologue*'. In their survey of over 400 recent graduates, Inglis et al. [15] report that in relation to the style of university teaching many respondents *'wrote about the need to make lectures more interactive and engaging'.*

Lectures have an important role within the undergraduate mathematics learning experience [16], but they form only one of the teaching and learning approaches that students will encounter. In recent times, universities have offered students increased choice in how, and when they learn with a range of additional opportunities also being made available. Whilst such a 'blended' approach [17] offers students greater choice, it places an increased emphasis upon the students themselves to access the available provision. In exploring the way in which those students studying mathematics, or subjects with a large mathematical component, used three learning resources (attended live face-to-face lectures, accessed online recorded lectures, and visited a mathematics support centre) in a blended learning environment, Inglis et al. [18] found that of the four strategies that emerged '*none involved making heavy use of more than one resource*'. This not only indicates that students have their own preferred ways of learning, but also that students learn in different ways; as such it is important for a department to provide students with a range of learning opportunities.

We have so far focused upon the challenges encountered by specialist students when learning mathematics at university, however we can also identify from the literature the aspects that contribute to a positive learning experience. A major finding identified by Brown et al. [11] '*related to the extent to which students felt part of a mathematical community'*. This was linked to the availability of a social study space within the mathematics department, near to staff offices, where students could work together, and also because its positioning facilitated interaction with staff since students '*could 'catch' lecturers going to and from these offices, as well as make formal and informal appointments to discuss various concerns*.' The importance of opportunities for dialogue with staff and their peers as part of student learning in mathematics has been reported elsewhere. Williams [14] investigated the experience of students making the transition to mathematical study at university from school or college and as part of the research asked them to rate their opportunities to ask questions and discuss ideas at university compared with school. He concluded that, for those making the transition to university study in mathematics, '*negative feelings are generally associated with a perception of poorer dialogue when students enter university programmes, and vice versa*'. Perhaps more significantly, he also found that '*interactions with lecturers were often fewer and less engaging than students had expected, and this was associated with a negative view of the university experience*'. A second finding emerging from the work of Brown et al. [11] was that '*positive attitudes related to students being able to share their ideas/problems with other students*' and as such indicates the importance of peer communities. Croft et al. [19] reinforce these findings and found that for some students, it is their peers they first turn to when they require support with their learning of mathematics, and in the survey of Inglis et al. [15] fifteen out of sixteen unsolicited references to peer support referred to its benefits.

There might be a tendency amongst some to consider students who experience the 'cooling-off' effect as 'failing students', however this should not be the case. As Croft and Grove [5] significantly note in their review of the literature these '*are not failing students…many are doing rather well.*' What differentiates those who go on to be successful when compared to those who fail and drop-out is that the successful students develop new ways of working or their own coping strategies [11,20]. Brown et al. [11] note that amongst some who were struggling they '*seemed to lack immediate sources of support and the motivation to seek these out*' and Goulding et al. [12] also highlight students feeling unsupported when struggling with their studies. As we have already seen, peers form an important source of such support.

### *1.2. Mathematics support and the mathematics support centre*

Mathematics support forms a '*facility offered to students (not necessarily of mathematics) which is in addition to their regular programme of teaching, lectures, tutorials, seminars, problems classes, personal tutorials, etc.*' [21]. Whilst it may have originally been aimed at those within the science, technology, engineering and mathematics (STEM) disciplines, it now also forms a means of addressing the 'mathematics problem' observed in a wide-range of disciplines including business and finance, health and biological sciences, and the social sciences [22]. The case for mathematics support in addressing the mathematical challenges of non-specialist students has been extensively articulated elsewhere (see [6] for a comprehensive overview) and as such is not repeated here.

Mathematics support can take many different forms, however one of the most popular means is that of the mathematics support centre. A mathematics support centre forms a physical location, staffed by tutors, where students can drop in at any time during its hours of opening to receive advice on their mathematical queries. In their most recent review of the extent of mathematics support provision within the UK, Perkin, Croft and Lawson [23] identified that '*the dominant provision is drop-in support*' with 74 of the 103 responding institutions offering mathematics support through a drop-in centre model.

The prevalence of drop-in mathematics support is not unique to the UK. In a 2015 audit of mathematics support provision across the island of Ireland [24] 25 out of the 30 responding institutions were identified as offering mathematics support; in 16 of these the dominant form of provision was through a drop-in centre. A similar situation has been observed in Australia. MacGillivray [7] reports on a 2007 survey of provision which found that 32 out of Australia's 39 universities had some form of learning support in mathematics and statistics with the most commonly-offered type of assistance again being the drop-in model.

Lawson, Croft and Halpin [25] identified that students value mathematics support and their reasons for doing so. They found that students particularly value the provision because *'it provides them with the opportunity to receive one-to-one assistance from a sympathetic tutor who is willing to take time to explain things to them. Furthermore, students also value highly being able to use the centre at times which are convenient for them rather than at times which are determined for them.*' Carroll and Gill [26] report similar reasons for student engagement but also found that their mathematics learning centre was having a positive impact with students '*because it* *helped them to gain a greater understanding of mathematics*', with a number commenting that the tutors in the centre '*helped them achieve greater understanding than the lecturers*'.

### *1.3. The specialist and more-able mathematics student*

There is much evidence that specialist and more-able students are also choosing to access mathematics support. Pell and Croft [27] found in their institution that the centre was '*used more by the better students who are seeking excellence, than by less able student who are looking to avoid failure'* and as such '*the mathematics support model has moved from one of remedial support to one of enhancement*'. Similarly O'Sullivan et al. [28] identified that mathematics support '*was not viewed by students only as a remedial support but rather, utilised by those students seeking to improve their understanding of mathematical concepts*'.

Croft et al. [29] report on an action research project that established a learning space for specialist mathematics students in year 2 and beyond. They note that the motivation for this was a result of the existing mathematics support centre becoming so busy there was a need to restrict it to year 1 students only. Evidence obtained from those students who used the new learning space indicated they were using it for social learning and that '*many students attend the centre in groups to work informally on coursework problems*' and '*peer support within these groups is often clearly evident*' [29]. Solomon et al. [8] also highlight the important role that mathematics support centres can have as spaces for facilitating social learning in mathematics, but MacGillivray [7] goes further when discussing the use of mathematics support by specialist mathematics and statistics students in one Australian university. She notes that not only are there '*students in the 'mainstream' mathematics and statistics courses with a diversity of capabilities for whom MSLS* [mathematics support] *is meeting a* *need*' but that there '*is also strong association between even minimal usage of MSLS and progression in mathematics/statistics programs*.'

There have been many studies that explore student engagement with mathematics support, however it is the case that the majority focus upon students from disciplines other than mathematics. In the overall current body of mathematics support research there is little work that focuses upon the specialist mathematics student, and even less that considers specialist and more-able mathematics students beyond the first year of their studies.

The work that we now go on to describe has been motivated by the usage patterns observed within a mathematics support centre in a large UK research-intensive university. We set out to answer the following research questions: 1) to what extent is use made of the mathematics support centre by specialist mathematics students? And, 2) what are their reasons or motivations for the usage patterns observed? As we shall see, usage of the centre is not only dominated by specialist mathematics students, but it is primarily those in years 2 and 3 of their studies who take advantage of the support on offer.

The work described here differs from that in the small number of studies currently in this area. Whilst the use of the mathematics support centre space for peer learning may have been a motivating factor for some specialist mathematics students attending the centre under consideration here, it is known from discussions with the tutors themselves [30], that the majority of visitors were instead accessing the centre to *specifically* seek mathematical help and guidance from a tutor.

## 2. Local context

In September 2012 a mathematics support centre opened for the first time within a large UK research-intensive university. It was developed with the support of the **sigma** mathematics and statistics support network [22] which enabled access to expertise from Loughborough University Mathematics Education Centre to inform its development [31]. The centre had its own dedicated room within the university library but was not located in a prominent location and as such was only likely to be found by those seeking it. It was able to accommodate around 10 students at any one time, and contained student workspaces, computers, books and printed resources. Initially opening for three hours per day (excluding weekends) during term time, it was promoted to students across the university by a variety of means including posters, postcards, awareness raising by academic and centre staff during lectures, and through the use of student ambassadors. By January 2015 the centre was opening for six hours each day during term time (again excluding weekends) and this has remained the format since.

For the start of the 2016/17 academic year, a significant change occurred when the centre moved to a new location within the newly-built replacement university library. It now occupies a spacious room within a prominent location, highly visible from the main staircase, and can accommodate approximately 20 students. Facilities remain similar with the exception that there are two large ‘whiteboard walls’ and presentation viewing screens. Whilst the room forms a dedicated support centre during its hours of opening, the room is available as a student study space outside of these times.

Since its establishment, postgraduate students have always been the tutors who work in the centre. They work in pairs for three hours at a time, and receive hourly payment for their endeavours. Since the move to the new location in 2016, all tutors have been from the mathematics department and studying for PhDs in either pure, applied or management mathematics or statistics. Their role and experiences within mathematics support have recently been explored elsewhere [30].

Since the mathematics support centre opened, attendances have been recorded to observe the number of visits and collect user information (name, student ID, year of study, academic programme, and nature of support sought). Originally students would sign in on paper-based sheets, however to coincide with the move to the new location, students were asked to sign in electronically upon arrival. As we shall discuss below, whilst there are some challenges with analysing this captured data, it has nevertheless allowed the overall usage of the centre to be monitored.

The support available in the centre has always been particularly targeted at foundation and first-year undergraduate students from all disciplines and programmes of study, and at students from other year groups identified as having particular difficulties with introductory mathematical and statistical techniques; in all of the promotional activities for the centre undertaken over the years, this messaging has not changed. However, whilst Table 1 shows that there has been a steady growth in the usage of the centre (the anomalous case of 2017/18 will be discussed later), there has always been significant use of the centre by specialist mathematics students, and in the last two years, they have very much formed the primary users. It is these observed attendance patterns that have motivated this work to try and understand why this particular cohort is using mathematics support so extensively.

## 3. Research Methodology

The research methodology for this study consisted of two components. The first comprised an analysis of collected support centre usage data from the last six consecutive academic years, and the second was a survey targeted at specialist mathematics students studying within the university. Ethical approval was granted by the university and appropriate ethical guidelines [32] were followed.

As noted previously, usage data for the centre has been collected since it opened in 2012. This engagement data was input directly by students themselves upon arrival. Whilst tutors are asked to encourage all users to sign in, this is not always possible, particularly at busy times, and as such it is known that the attendance of all users has not been logged. This, coupled with a failure of the online attendance logging system in 2017/18, has meant that the figures for 2017/18 (Table 1) are much lower than their reality. Nevertheless, they have been included as the in-year trends remain highly relevant to our work.

Prior to the analysis of the attendance data, the names of all individual users were removed such that seven digit 'Student ID' remained the only means of tracking users. The data was provided by students at each visit, and some of this data was subsequently transferred for storage in an electronic format from paper-based records. As such there existed errors in the data including misread entries, typos and blank entries that required a process of data cleaning. Where identified errors could not be corrected, the entries were disregarded. Overall, no more than 20 entries were disregarded in total. The challenges posed by several factors, including the integrity and accuracy of the data, when attempting to use it to investigate the impact of mathematics support provision has been discussed by Matthews et al. [33].

The survey was circulated in autumn 2017 to all students within the mathematics department (n≈800). It contained 24 questions (listed in Appendix 1) to ascertain mathematical backgrounds, their views on the current learning activities and opportunities they receive to aid their mathematical learning, and a series of questions relating to the mathematics support centre and their use of it.

## 4. Results and analysis

### *4.1. Support centre usage patterns*

Table 1 demonstrates that the overall number of visits to the support centre has been increasing year-on-year. Most interesting, however, is that in the five-year period up to the end of the 2016/17 academic year, whilst overall visits have more than doubled, the number of visits made by specialist mathematics students has increased by almost a factor of five. In 2016/17, four in every five recorded visits to the centre were made by a specialist mathematics student.

Given the remit, and promotion of the centre to support students at the transition to university, it might therefore be reasonably expected that the growth in usage from specialist mathematics students comes from those in year 1 of their studies. Further interrogation of the data, however, reveals this not to be the case (Table 2). The proportion of visits made by specialist mathematics year 1 students has declined over time from just under two-thirds in 2012/13 to just over 20% in 2017/18; over the same period, the proportion of total visits made by specialist mathematics students in years 2 and 3 combined has increased from just under a third to around 70% (with a peak of almost 80% in 2016/17). Whilst there are evidently more visits to the centre, and indeed a greater number of unique users accessing the provision, its move to the new location (start of 2016/17 academic year) appears to have had little effect upon the *proportions* of students from each year group who choose to visit.

Within mathematics support centres, it can be unclear from headline usage statistics as to whether the students making the visits are first-time users or returners making multiple visits. Our data allowed the ability to track student usage *across* academic years as shown in Figure 1.

Figure 1 represents both the number of unique (specialist mathematics) student visitors to the centre within each year group (either an integer or the denominator if shown as a fraction) along with the number of these unique visitors who also made use of the centre in a *previous* academic year (the numerator of the fraction). An example will make this clear. Amongst the cohort who began their studies in year 1 in 2012/13 there were 44 unique visitors to the support centre. In 2013/14, and when these students had progressed to year 2, there were 29 unique student visitors in year 2; of these 29 students, 18 had previously made a visit to the centre when they were in year 1. In 2014/15, and when this 2012/13 starting cohort had progressed to year 3, there were 30 year 3 unique visitors to the centre; of these 30 students, only 9 had previously made use of the centre when they were in year 1 and year 2 of their studies.

What the data show is that whilst some of the centre's users *each year* are evidently returners, the majority are in fact new users. Of the individual students who used the centre when they were in year 2 (201 students), only 33% (67 students) had used it previously in year 1. Similarly of the 205 unique users from year 3, only 29 (14%) had accessed the support offered by the centre in both of their two previous academic years. This suggests that whilst some specialist mathematics students are perhaps reliant upon mathematics support throughout their programme of study, the overall proportions are small when we get to year 3; the majority appear more strategic in their use of it choosing only to do so as, and when, a specific need arises. Nevertheless, in the case discussed here, the dominant use made of the support centre by such specialist mathematics students indicates it plays an important role in their mathematics learning experience.

Whilst these data offer an insight into how the centre is used by specialist mathematics students, particularly in the later years of their studies, they cannot explain the reasons behind these usage patterns. To offer greater insight, we now turn to the results of the survey that was conducted amongst specialist mathematics students who were both users and non-users of the centre.

### ***4.2. Survey of specialist mathematics students***

#### *4.2.1. Respondent backgrounds*

The survey attracted a total of 47 responses representing a response rate of approximately 6% amongst the target population of specialist mathematics students. Whilst this is lower than we would have liked, it is consistent with other optional student surveys that have been undertaken in the department. Of the respondents, eight were studying on joint honours programmes, but in all cases mathematics formed at least 50% of their studies. They were distributed across all academic years: five respondents were year 1 students; 10 were from year 2; 16 from year 3; and, 16 were from year 4.

The profile of respondents indicates they were amongst the most mathematically able within their cohorts and as such not expected to unduly struggle with the mathematical demands of their course when beginning their studies. All respondents entered the university with some of the very highest grades; in the UK's A-level (pre-university) qualifications system, this would have been at least AAA in three subjects, one of which was mathematics. Additionally, of those who had completed their pre-university qualifications within the UK, 79% had also studied an A-level in Further Mathematics. Further reinforcing that the survey responses overall represent a mathematically able cohort, 85% had not failed a mathematics module whilst at university, and 11% had failed only a first year module (or modules).

### *4.2.2. In-course learning opportunities and support*

Lawson et al. [25] note clearly that mathematics support forms an offer which is *in addition* to the regular teaching that students receive as part of their studies. However the current reality of this definition is not quite so clear-cut. Students will not only receive a range of *in-course learning opportunities*, that is teaching sessions, resources or feedback with which they will be expected to engage, but mathematics departments are increasingly providing additional, and most importantly voluntary, opportunities for students to consolidate their learning. We choose to call this *internal learning support* and it includes a virtual learning environment (VLE) resources, peer support sessions, lecturer office hours, and indeed mathematics support centres. There also exists what we call *external learning support* that forms further voluntary opportunities for students to enhance their mathematical knowledge, skills and understanding which may not only be external to a mathematics department but also the institution itself. Examples include friends, websites and online videos, textbooks and private tutors.

To understand why specialist mathematics students choose to access mathematics support, and in our context we specifically mean the mathematics support centre, it is helpful to understand their views on the wide range of learning activities or opportunities that are available to them. Respondents were asked to indicate how often they used 15 learning activities or opportunities that we have divided into the three categories noted above. The results are shown in Figure 2. It should be noted that at this stage, and given that the mathematics support centre formed a specific theme of questioning in the later sections of the survey, it was deliberately not included as a possible response here.

When considering responses for the *in-course learning opportunities*, lecture notes (96% of respondents) and lectures themselves (89% of respondents) were identified as being the most frequently used. Whilst the results for tutorials (groups of approximately 6 students meeting weekly with an academic tutor to discuss and receive feedback on their submitted work and tackle additional mathematical exercises) may appear surprising, there exists a local context in that they are only offered to students in year 1 and year 2; 11 out of the 12 students who said they never used these were from either year 3 or year 4. If the responses for tutorials are restricted to those in year 1 or year 2, 60% of students indicated that they used these 'a lot'. Most surprising were the responses for example classes. These are large informal classes, offered every two weeks, where students attend to work on an exercise sheet associated with a corresponding lecture course, with support typically provided by a member of academic staff and postgraduate teaching assistants (PGTAs), yet only 51% of students indicated that they used these 'a lot'.

Opportunities classified as *internal learning support* were much less well used with three of the five forms of support (recorded lectures, peer assisted study support (PASS) provided by Year 2/3/4 student volunteers to students in all years of study, and departmental-based drop-in help sessions) being 'rarely' or 'never' used by over 50% of respondents. Additional resources placed on the VLE, to complement lectures, were overwhelmingly the most well used with 57% of respondents indicating they used these 'a lot'; whilst lecturer office hours were used at least 'a little' by 53% of respondents, we choose to discuss these in more detail later. Of the *external learning support*, friends were identified as the most common with almost 80% of respondents indicating that they used such opportunities regularly.

*4.2.3. Engagement with the mathematics support centre*

Of the 47 specialist mathematics students who responded to the survey, 25 indicated that they had used the mathematics support centre at some point during their studies. Reinforcing that those using the centre represented a mathematically-able cohort, 23 of these 25 centre users indicated that they had never failed a mathematics module whilst at university.

How frequently the centre was utilised by respondents varied. Whilst around a third of students indicated that they used it more than once a fortnight, almost a half indicated that their usage was no more than once a term. Some students appear to be reliant upon mathematics support if they do not understand the content of lectures:

> They have retaught me things the lecture could not convey clearly, which helped my general understanding.

> I find it easier to understand a topic when it is explained again, by someone who has the time.

For others, it is accessed as a source of help as soon as difficulties are encountered with the assessed components (problem sheets) of their studies:

> I always use it for any problems I'm stuck on for assessed problem sheets.

> It has helped me on numerous occasions when I have been stuck on assigned work.

However for many others their use is more strategic and occurs as, and when, a specific need arises:

> Helped me understand a key concept in a course last year.

> Because it helped me understand an important fundamental of degree level mathematics.

Regardless of how often students made use of the centre, the primary motivating factor for its use was to gain assistance that would enable them to tackle the assessed problem sheets for themselves. Whilst the centre's tutors are instructed during training that they may provide guidance on the concepts associated with assessed work but that they should not tackle the actual problems themselves, the enhancement of grades for assessed tasks was the motivation for 75% of respondents:

> It helps to cement understanding in concepts of maths, and also to be able to answer assessed assignments leading to better grades.

> I can ask questions on topics I am unsure about so I can do my problem sheets and get better marks in my modules.

Those who indicated that they had made use of the mathematics support centre were asked whether they felt it had contributed in some way to their success whilst at university. The results in Table 3 show that just over 70% of users reported that they felt the use of the centre had impacted positively upon their success. Whilst several references were made to the centre helping with the completion of assessed problem sheets, a more prominent feature (nine responses) was an indication of how users felt the centre had contributed directly to developing or enhancing their mathematical understanding:

> Helps break down parts of the course in another way and a way I can understand.

> Given some confidence to my answers and increased my understanding to the work.

> They have helped me understand various aspects of the course.

The impact of the centre upon perceived success was not only restricted to frequent users (i.e. those who used the centre a minimum of once a fortnight); 10 of the 18 students who answered positively were much less frequent users with seven of them visiting at most once a term.

Whilst respondents were less clear on whether, and indeed how, their usage of the centre had impacted positively upon their mathematical confidence and/or motivation, just over half indicated that it had. Some students reported that using the centre had increased their confidence in their knowledge of a particular topic or their ability to solve problems, but for others, it was more about providing reassurance of their existing abilities:

> I'm more confident as I see that I can answer these questions, just needed a little guidance.

> With my answers, sometimes I go to check my answer and it's already correct.

This development of confidence and motivation was not only in relation to the mathematics itself, but also in their subsequent desire to ask further questions and seek help to aid their own mathematical learning:

> I am motivated to understand a topic more so that I can ask further questions.

> More motivated to ask questions

> More confident in asking for help. More confident in my mathematical ability.

Even amongst non-users, simply knowing that support was available if needed was a motivating factor:

> I'm more confident that I know there is support there if I need it and this makes it easier when struggling with problem sheets to persevere.

The survey initially asked students to identify their preferred learning activity or opportunity from the 15 available types shown within Figure 2. Students who indicated that they were users of the mathematics support centre were asked to rate the assistance it offers to their learning of mathematics with that of the other learning activities and opportunities available to them as part of their studies. Over half indicated that the mathematics support centre was better than other learning activities and opportunities they encountered, and a further 40% felt it was no different. Interestingly in the case of the one respondent who indicated that it was 'much worse', they had previously indicated that using the centre had not only contributed to their success at university, but also their mathematical confidence and motivation.

Given these observed student views, and coupled with their usage of the centre, its perceived impact upon their success, confidence and/or motivation, there exists clear evidence that, amongst a mathematically-able cohort, there are students for which the mathematics support centre is meeting a perceived learning need. This is true even for those who are not frequent users of the centre. As we shall see in Section 5.2., we have been able to identify a series of reasons as to why the mathematics support centre is popular with the specialist, and more-able mathematics student, and as such why they choose to access it as an important component of their learning experience.

## 5. Discussion

### *5.1. Engagement and non-engagement with learning opportunities and activities*

Evidence emerging from the survey shows that there is generally a high level of engagement by students with those learning activities and opportunities that involve the provision of mathematical *information* that is the same for the entire cohort. Examples include lecture notes (96%), lectures (89%) and VLE resources (57%). For the more *personalised* learning activities and opportunities, that is where students can receive guidance on their own work, ask questions, or discuss ideas, and where engagement with these forms an expected component of their studies (tutorials (60%), feedback on work (53%) and example classes (51%)) there were more moderate levels of use. The voluntary opportunities for personalised learning (departmentally organised peer support (11%), departmental drop-in sessions (9%), and lecturers' office hours (6%)) were very much less well used and valued. In all cases, the figures in parentheses show the percentage of respondents who indicated they made use of these learning activities and opportunities 'a lot'.

From the 15 learning activities or opportunities identified in Figure 2, respondents were asked to identify which was their most preferred. Lecture notes (32% of respondents) was the most popular response, and in agreement with the findings of Brown et al. (2005), some respondents even went as far as indicating that lecture notes were the only resource they needed for their learning:

> Lecture notes as they're detailed and contained everything you need.
>
> If I am just concerned with getting by in the module and exam preparation, my preferred form of support is my notes from lectures…

Friends were also explicitly referenced by 30% of respondents with the key reasons being that they not only offer a more readily accessible or convenient form of support, but that they can also offer tailored or personalised explanations, and there is far less fear associated with how questions might be received when they are asked:

> Asking my friends because I often feel like I can ask them simpler questions without worrying about appearing daft. Also I feel that I can ask them more specific questions and I can talk more informally with them.
>
> Friends, we usually get through the work and problem sheets together and we break it down in a way that each other can understand. It is also the most accessible.
>
> Friends because it's not embarrassing to admit I don't know what's going on, and we work together.

The importance of friendship groups in the learning of mathematics has been noted by others [11,12], with Croft et al. [19] commenting that '*a key finding from our focus groups has been that many students value, first and foremost, the support of their peers*'. As a consequence departments, recognising the benefits of students working collaboratively on mathematical tasks have sought to establish peer assisted study support (PASS) or similar peer mentoring schemes to formalise the process of students, usually in later years, helping support those in earlier years with their mathematical learning. Whilst there are known benefits for student learning outcomes from peer support [34,35], it is interesting to note that here students specifically referred to 'friends' rather than 'peers' and this was in relation to self-organised groupings. In fact, and consistent with Goulding et al. [12], whilst students do value peer support they prefer to instigate this themselves rather than it being organised by a department:

> *…it's just a group of random people that I don't know that I've been told to be friends with, and I have nothing in common with them and I'd rather choose my own friends, even if there's less of them.*

The 47 respondents to the survey indicated a wide range of preferred learning activities and opportunities (13 different types), but exploring their reasons for these choices identifies a broader trend. Over 50% of students made some form of reference in their preferences to 'dialogue', that is opportunities to engage in some form of a discussion in relation to mathematics with others. In a number of instances, this was explicitly linked to seeking answers to questions they had:

> Tutorials, because you can have both peer and lecturer interaction, and you can ask questions about any module.

> Office hours, you can ask specific questions on a 1 on 1 format where they are always willing to help and encourage you to think for yourselves.

With this evidence of students, across all years, valuing dialogue in relation to their learning, it is perhaps a surprise to see almost a quarter of respondents citing example classes and lecturer office hours as their least preferred forms of learning support. Such sessions have been designed to provide opportunities not only for mathematical discussions to take place, but also for individual questions to be answered. For example classes, whilst one student identified that they worked as intended:

> …because you can get help on the work…and the people there (usually) know what's been covered in lectures and how to help with all of the questions you have.

For others, it was a less positive experience due to them either lacking a formal structure, or more commonly, because they do not offer the opportunities for dialogue that students are seeking:

> They're [the tutors] reluctant to answer questions for fear of giving away the answer.

> Often there are not enough people available to take time to spend working through the problem with you.

With regard to lecturer office hours, the responses are much more concerning as several students reported that they felt intimidated or uncomfortable when speaking with members of staff:

> Some lecturers make it feel patronising if you don't understand something.

> Some seem reluctant to help and make you feel stupid.

Not all students indicated that it was the staff members themselves they found intimidating, but more the process of going to the office of a lecturer to engage in discussions about mathematics, particularly if they do not feel their knowledge is at the level they think it should be:

> Lecturer office hours [are my least preferred form of support] because I feel that I have to ask a complicated question and be up to date with everything else that I've learned until then for it to be useful, and often that isn't the case.

But there were indications that students would feel more comfortable engaging with staff members if these discussions took place in a student-space [8] rather than a staff-space:

> I don't feel comfortable to go and talk to them about issues I may have, maybe do something like the Drop In sessions but with lecturers in the MLC [mathematics student learning centre].

Although many students made reference to the importance of dialogue in their responses, there were still a number of clear reminders that amongst some, the study of mathematics can be a solitary discipline. In several responses this was linked to a lack of confidence in sharing their ideas and working with others, but in others it was a conscious choice to work independently:

> I am often too shy to ask questions at example classes, so I never seek out PASS or drop-in sessions.

> Not confident doing maths in front of others. Some people are not approachable to aid with teaching.

> I am not a sociable person. I prefer to work on problems on my own

Finally, and generally, students indicated that the timing and convenience of learning activities and opportunities were also important factors in whether or not they chose to make use of them. For some students, this choice was due to timetabling constraints or external time pressures:

> Office hours because I have to go into uni more often.

> I either don't have time or aren't available at the hours specified. . .

But for a small number of others, the speed at which they could seek a resolution of their queries was a motivating factor:

> Quicker to ask friends or watch lectures or look at lectures notes than sit in PASS sessions.

> Websites [are my least preferred], as it often difficult to access the required information quickly…

From our analysis, it is evident that the mathematics department-led personalised learning opportunities offered to this cohort of specialist mathematics students are not completely meeting their needs or their expectations. In particular we note issues with:

- A perceived lack of opportunities for students to engage in discussions about their own work or learning;
- A perceived lack of opportunities for students to ask questions, or a reluctance to do so, perhaps as a result of cohort sizes or a non-conducive environment;
- Students feeling intimidated or uncomfortable when engaging with members of staff;
- Some students, through choice or otherwise, not having ready access to support groups to which they can turn in support of their learning when needed;
- The timing and convenience of access to some learning opportunities.

Given these issues, there is evidence here that students are not only turning to their friendship groups, where they exist, as a means of obtaining personalised learning support, but with the availability of a mathematics support centre they, along with those who do not have established peer support groups, are also making use of this to enhance their mathematical learning. Croft and Lawson [36] argue that whilst the mathematics problem may not be solved for mathematics students, '*mathematics support provides a* *proven way of mitigating some of its worst effects*'. Amongst those who indicated that they use the mathematics support centre more than other forms of support available to them we can begin to see how its use mitigates some of the issues we have noted above:

> Better than example classes because it's easier to get 1-1 help, and you aren't limited to the hour example class.

> Shorter wait to see a postgrad than example classes.

> I prefer the one to one experience provided by the Mathematics Support Centre, as it is more personal.

### *5.2. Understanding engagement with mathematics support*

Emerging from the responses of specialist mathematics students themselves, we now go on to identify four reasons as to why they choose to use a mathematics support centre and the benefits that this offers to them and their learning experience. As we shall see, whilst several of these are characteristics of mathematics support, and as such are not unique to this cohort, there is a specific local context (Section 5.2.4) which appears to be a factor in students choosing to use this particular centre.

#### *5.2.1. Convenient and timely*

Carroll and Gill [26] report that the students visiting their centre greatly value knowing when support is available and the convenience of being able to drop in at times that suit them. Respondents here reported similar benefits noting particularly the extensive and consistent availability of support:

> It is much more consistently available than the other forms of aid.

> …[It] is on more regularly so is convenient and it is good that you can drop in at any time.

> The hours that the PhDs are there is flexible around our timetable.

But not only that, the centre was also cited as being able to provide a source of *immediate* help when students experience difficulties with their learning or understanding of mathematics.

> It's very convenient and instant help. Emailing lecturers can take a week to get help, and example classes the same.

> 1-1 contact is far superior in my opinion to re-reading lecture notes or looking for help online.

> It is much easier to speak with someone who can help me in most, if not all, my modules at the same time.

This is particularly important given the fast-paced nature of university mathematics courses or if students are facing an impending assessment deadline. However, and as Lawson et al. [25] also note, the perception of the immediacy of the mathematics support centre as a form of learning support can make it difficult to manage the expectations of students, particularly at busy times:

> Sometimes there is not enough support staff to meet the demands of the people available.

*5.2.2. Personalised nature*

It has long been known that one of the aspects most valued by students who make use of mathematics support centres is the one-to-one (personal) help that it allows them to access [37]. Again, this aspect was widely cited by students here:

> Personal and specific assistance and feedback.

> People are always helpful and you receive one to one help.

More broadly though, in terms of the benefits it offers to student learning, such personalised instruction has been cited as one of the "*pedagogical approaches that are linked to enhancing student learning, involvement, and engagement beyond simply making the coherence of the educational experience clear to students*" within higher education [38]. This reinforces that in order for there to be longer-term benefits to learning, the student must be an active participant in the process. As such, a student visiting a mathematics support centre merely to be 'told' the answer is clearly insufficient. A number of respondents did recognise that using the mathematics support centre offered the opportunity for:

> a more interactive way of learning.

with others going on to clarify how such an approach can actually lead to them finding the answer to their original question through their own endeavours:

> Explanations are always clear and I often get given points and find the answer on my own which increases my understanding.

We have seen (Section 4.2.3) that there is evidence of students visiting the mathematics support centre to seek reassurance of their existing mathematical abilities from tutors.

Being supported through a problem on a one-to-one basis can reinforce that students already possess the necessary mathematical knowledge and skills to be successful at a problem, and as such this helps with the development of their mathematical confidence. This process of reassurance and building confidence within students is important in the context of their overall learning experience because, as Solomon and Croft [39] argue, '*'undoing' alienation and enhancing engagement at university rests on the development of new relationships with mathematics through greater support for students' developing confidence in independent mathematical judgement*'.

A personalised approach, however, places particular demands upon the tutor. Not only must they possess a wide mathematical understanding of the topic, but also well-developed pedagogic skills to be able to lead the student through the problem using questioning, examples, and alternative explanations. Most significant is not simply 'telling' the student the answer. Whilst we shall discuss the skills and abilities that make for a good mathematics support tutor in Section 5.3, several respondents were quite clear that they didn't want their visit to the mathematics support centre to simply 'reveal' the answer, but instead wanted the answer to develop as a result of an interactive process between themselves and the tutor. Indeed this ability to be successfully 'led' through a problem was one of the skills students indicated they most valued in a tutor:

> Someone who doesn't tell you the answer but guides you towards finding the answer yourself.

> The ability to guide the student to the correct answer without explaining all the details, i.e. act as a helping hand instead of giving the answer.

> Ability to explain a concept in different ways - working through examples to further students' understanding of the concept.

*5.2.3. Informal and flexible learning environment*

The informality of the mathematics support centre environment emerged as a common theme amongst respondents:

> Individual help on a specific question in a friendly environment.

> Allowed me to get expert advice without feeling the pressure.

> It is a nice chilled environment where the staff are more than ready to assist.

with comments then being linked to the role of the tutors in building that friendly and supportive environment. In particular the willingness of the tutors to help individual students was commonly cited:

> PGTAs [Postgraduate Teaching Assistants] are generally very helpful and eager to help the students who go.

> PGTAs are a great help and will consistently help you to try and understand the issue.

> Great guys, approachable, very intelligent.

There was also evidence that the students welcomed this environment as an opportunity to engage in informal conversations with a tutor about mathematics:

> Postgrads are really nice, if they don’t know the answer they will point you in the direction of someone who does. Also nice to be able to just talk maths through sometimes.

The existence of peer communities is known to be important for non-specialist, or service users, of mathematics in encouraging their engagement with mathematics support, particularly as a means of overcoming fear [40]. Similarly, for the specialist and more-able mathematics student Croft and Grove [5] comment that in the context of student perceptions of their mathematical learning experience the '*importance of supportive staff and peer communities should not be underestimated'*. Brown et al. [11] reported that students who had a more positive attitude towards their studies of mathematics were those who shared their ideas and problems with other students. Although there were by far more comments from students about working with a tutor, there were nevertheless a number of students who made use of the mathematics support centre as a location for working with their peers, typically on assessed tasks:

> Very helpful for problem sheets and working together on a problem.

> …other people are generally doing the same problem sheets are generally there too so everyone can help each other.

We have seen that the attempts organised by the mathematics department to facilitate peer learning have not been well accessed by the students, but by providing a suitable location, students are quite willing to organise their own learning communities. As Solomon et al. [8] note '*the value of providing space for students to develop their own communities of practice*' is reinforced here. However, whilst Solomon et al. [8] quite rightly argue that a quality learning experience for many students '*includes the provision of spaces and resources within those spaces which facilitate student interaction and peer support*' we have seen that for some students, the study of mathematics remains an independent pursuit. Mathematics support centres have the ability to cater for a range of student learning preferences in one common facility: they can provide a suitable space for social learning, a location for those who wish to study independently whilst on campus, and a location where guided learning can be provided by a tutor. Indeed as one student put it:

> It strikes me as a better version of PASS/drop-in-sessions in one place.

### *5.2.4. Skilled, knowledgeable and approachable tutors*

We have seen evidence that the interpersonal skills of the tutors working in the centre contribute to establishing its informal and welcoming nature. Their friendly manner, understanding and empathy were particularly noted by students; this is in clear contrast to the perceived approachability of some teaching staff highlighted by several respondents:

> It is another resource that can help students, and sometimes the lecturers can be a bit intimidating to talk to.

> . . .postgrads less scary than lecturers.

> A place where you can go to ask knowledgeable people who aren't lecturers. . .

Whilst Lawson et al. [25] note that '*it is of some concern that less than half the students interviewed regarded mathematics teaching staff as helpful'* our findings do not raise issues with the helpfulness of teaching staff per se, but instead highlight that some students perceive staff as intimidating and as such difficult to approach. This is an important issue as it impacts upon their opportunities to engage in dialogue as part of a mathematical community [14], which then has consequences for their sense of belonging to that community [11]. To mitigate this, a number of the specialist mathematics students in this cohort appear to be engaging in discussions with postgraduate tutors in the mathematics support centre. By doing so they recognise that they can receive explanations that they find more understandable and by tutors they deem more approachable:

> It has people with a lot of subject knowledge, but who also have the ability to explain things in a simpler way than the lecturer sometimes can.

> Someone who can explain something in a different way than your lecturer, but who understands the content well.

> Their ability to break down complex concepts into simpler ones.

What is interesting here is that whilst students recognise the strong mathematical backgrounds of the tutors, they particularly recognise the ability of the tutors to effectively communicate complex ideas and topics. This is something very different to the findings of Walsh [41] who found that tutors were far too didactic and made the material too abstract in teaching for their mathematics support centre. The challenge of this task for the tutors should not be understated; after all, these are year 2 and year 3 students dropping in to the centre, without warning, and seeking assistance with what are advanced mathematics modules in a research-intensive university.

As Grove et al. [42] have shown, it remains rare, although by no means unique, for a mathematics support centre to offer support to specialist mathematics students beyond the first year of their studies. The usage of this centre by these students is something that has naturally developed – it has never been promoted as being available to this cohort but neither has their use of it been discouraged. The reasons for student use appear linked to the tutors themselves as students recognise that the tutors have particular, and often specialised, areas of mathematical expertise that they actively seek out:

> You have to know which staff members [tutors] are working when as they all have their specialities.

> Often you had to go at specific times/dates so the people who know your module are there.

It is easy to see how users can adopt this strategic approach to seeking support once the local context is considered. In the last two academic years, not only have all of the centre's tutors been PhD students from the mathematics department, they have also all acted as PGTAs on departmental modules. They are quite visible to undergraduates within the mathematics department, and also highly familiar with the content of what, and how, students are being taught. Further, it is now the case that there are a number of postgraduates working as tutors who were previously undergraduates within the same department themselves only a year or two ago. They may be known to centre users in a more informal capacity, but perhaps more significantly they will have studied the same mathematics modules themselves and as such will be able to use their own learning experience to assist the student.

This level of familiarity between the tutor and the student does appear to alter their relationship. There exists evidence in the survey that some of the specialist students who make use of the centre actually view the tutors as fellow students or peers:

> Having other students explain things to you is a lot less intimidating and can therefore be a lot more understanding.

> Because other students (PhDs) are always available to help and there are a variety of potential questions that can be asked.
>
> Postgrads who have already done it.

Not only will such a relationship further contribute to the informality of the mathematics support centre, there is also evidence that peer tutoring in a university drop-in mathematics environment can lead to enhanced outcomes for those who choose to access the support [43].

### *5.3. The skills that make a good mathematics support tutor*

Postgraduates students working in a mathematics support centre will very much be at the beginning of their teaching careers and as such will have had perhaps only minimal training and limited experience upon which to base their practice. Whilst all tutors working in the centre described here received initial training, similar to the model described by Croft and Grove [44], it is also known that they develop their teaching skills through their practice in their centre and by being part of a community of mathematics support tutors [30].

Mulligan and Mac an Bhaird [45] comment that '*it may appear, to those not involved in MLS [mathematics learning support], that tutors simply help students when they get stuck*', however as we have seen, users have greater expectations of the process than this. They go on to note '*just because someone is good at mathematics or statistics, does not mean they will be a good MSC [mathematics support centre] tutor*'. As one of the respondents to our survey commented, it is the intersection of strong mathematical knowledge and experience, coupled with developed interpersonal skills and an empathy with what it is like to be a learner of mathematics that are the key qualities of a tutor in a mathematics support centre environment:

> The people were very helpful due to their knowledge and experience, and were also friendly and understanding.

Building upon this, respondents to the survey were asked to identify the specific characteristics that make for a good mathematics support tutor. In addition to the strong subject knowledge, ability to communicate effectively, a friendly and approachable manner, and the skills of guiding the student to find the answer without simply 'telling' already identified, empathy with what it is like to be a learner of mathematics, the ability to listen, patience, confidence in their own mathematical ability, and a genuine interest in student learning were also commonly cited:

> Ability to explain ideas in an easy to understand way. Also they should be confident and willing to help.

> . . .friendly, approachable, good at listening, explains things and supports you getting the answer without just telling you the answer. Making sure you understand it.

> Non judgmental! Not giving up and trying a different explanation when one doesn't work. Having the patience to work with the student from first principles to identify where the difficulty is.

> A good listener and not patronising if you don't understand certain things.

> Able to understand what the student is asking for help with and what they aren't understanding. . .

> Can listen to all problems, has empathy or understanding to the way you are feeling and can address it in a proper manner. . .

## 6. Conclusion

We began this study seeking to answer two research questions: 1) To what extent is use made of the mathematics support centre by specialist mathematics students? And, 2) what are their reasons or motivations for the usage patterns observed? In answering these questions we have shown that there exists a large cohort of learners studying single and joint honours programmes in mathematics, within a research-intensive UK university, for whom the use of a mathematics support centre is meeting a genuine learning need. These are not students in the early stages of their undergraduate studies, they are in year 2 or year 3, and neither are they students who appear to be unduly struggling with the mathematical demands of their course. Whilst there is some evidence, as other have previously noted, that students are making use of the mathematics support centre as an environment to engage in peer learning, for many they are using this opportunity to seek advice and guidance from the postgraduate tutors who work there to enhance their mathematical knowledge and understanding. A motivating factor appears to be the lack of uptake of the departmentally based opportunities, due to students feeling uncomfortable, their timing, or an insufficiently personalised experience, to engage in discussions about their mathematical learning. They are instead visiting the support centre where they can drop in at times to suit them, where they feel the environment is more conducive to a friendly and personalised experience, and where they feel part of a community amongst peers in which dialogue can freely take place. As we have seen in our consideration of the literature in the discussion above, these reasons are not unique to specialist and more-able mathematics students, they apply equally to non-specialist users of mathematics support.

There is wide recognition of the personal qualities of the postgraduate tutors in not only creating a learning environment within the centre that students find relaxing and welcoming, but that they also possess the subject knowledge and pedagogic skills to enhance their learning. The fact that tutors also act as graduate teaching assistants on the mathematics modules for which students are seeking help, or that they themselves have studied these same modules previously, does appear to be specific factors that encourage the use of the centre by the specialist mathematics students in the case we describe here. This is different from the situation which might be experienced by non-specialist students struggling with mathematical concepts taught by their home department who then choose to engage with mathematics support. In some instances centre users appear to consider the tutors as their mathematically more experienced peers. Whilst we can only speculate, the small proportions of centre users from disciplines outside of mathematics might imply that postgraduates, or postgraduates taken solely from a research-intensive mathematics department, may not be the appropriate tutors for all learners. This is an area that merits further study.

Our findings do have a much broader significance. They show the value that students place upon dialogue with others as a means of supporting or enhancing their mathematical learning and understanding. However even where departments provide a range of different opportunities for students to engage in mathematical dialogue with others, not all students will access these and this choice can often be a deliberate and considered one rather than as a result of a lack of interest or commitment. A lack of alignment with their preferred learning style was the reason given by 30% of respondents for their non-use of some learning opportunities, and feeling uncomfortable with a particular approach, or their own lack of confidence, were reasons given by others. As such, whilst it may appear that departments can streamline the learning opportunities they offer, students prefer to learn mathematics in different ways, and so catering for this variety of student learning approaches will continue to be important.

A mathematics support centre has the ability to successfully cater for students with a variety of preferred learning styles: those who wish to learn mathematics in a social way, i.e. with their peers, those who wish to learn independently in a relaxed and informal environment, and those who wish to engage in dialogue and seek expert guidance from skilled and knowledgeable tutors. Even amongst those who are not regular users of the mathematics support centre there exists evidence that some engagement with it impacts upon their perception of success whilst at university, and in some instances provides them with the confidence and motivation to engage by asking questions and seeking wider help with their mathematical learning. This is indicative of the powerful nature of mathematics support – one student visit may be sufficient to resolve a fundamental issue acting as a 'block' in a particular module or it might provide the confidence needed to support their learning. It is clear that, for a range of reasons, the mathematics support centre can meet an important learning need for the specialist and more-able mathematics student.

## 7. Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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## Tables

| | 2012/13 | 2013/14 | 2014/15 | 2015/16 | 2016/17 | 2017/18* |
|---|---|---|---|---|---|---|
| Total Visits: All Disciplines | 482 | 571 | 875 | 793 | 980 | 615 |
| Total Visits: Mathematics Only | 163 | 294 | 425 | 354 | 786 | 526 |
| | | | | | | |
| Percentage of Mathematics Visits | 33.8% | 51.5% | 48.6% | 44.6% | 80.2% | 85.6% |

**Table 1. Total visits to Mathematics Support Centre by Academic Year.** Note, all students who did not provide either their ID number or Programme of Study have been disregarded. 2017/18 represents only a partial dataset.

| | | 2012/13 | 2013/14 | 2014/15 | 2015/16 | 2016/17 | 2017/18 |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Year 1 | Number of visits | 105 | 110 | 126 | 94 | 130 | 107 |
| | Number of students | 44 | 34 | 22 | 13 | 48 | 32 |
| | Proportion of total visits | 64.4% | 37.4% | 29.6% | 26.6% | 16.5% | 20.3% |
| | | | | | | | |
| Year 2 | Number of visits | 53 | 99 | 214 | 130 | 307 | 182 |
| | Number of students | 8 | 29 | 27 | 25 | 73 | 47 |
| | Proportion of total visits | 32.5% | 33.7% | 50.4% | 36.7% | 39.1% | 34.6% |
| | | | | | | | |
| Year 3 | Number of visits | 0 | 59 | 75 | 116 | 319 | 180 |
| | Number of students | 0 | 16 | 30 | 22 | 84 | 53 |
| | Proportion of total visits | 0% | 20.0% | 17.6% | 32.8% | 40.6% | 34.2% |
| | | | | | | | |
| Other | Number of visits | 5 | 26 | 10 | 14 | 30 | 57 |
| | Number of students | 4 | 11 | 6 | 5 | 21 | 15 |
| | Proportion of total visits | 3.1% | 8.8% | 2.4% | 4.0% | 3.8% | 10.8% |
| | | | | | | | |
| **Totals** | Number of visits | **163** | **294** | **425** | **354** | **786** | **526** |
| | Number of students | **56** | **90** | **85** | **65** | **226** | **147** |

**Table 2. Usage of the mathematics support centre by specialist mathematics students only.** Note, the 'Other' category includes those specifying as MSci (Year 4), Postgraduate or Foundation Year students along with those whose identity was 'unspecified' or 'unknown'.

| | | Influenced mathematical confidence and/or motivation? | | | | **Totals** |
|---|---|---|---|---|---|---|
| | | **Yes** | **No** | **Unsure** | | |
| Contributed to success at university? | **Yes** | 11 | 4 | 3 | | **18** |
| | **No** | 0 | 2 | 0 | | **2** |
| | **Unsure** | 2 | 2 | 1 | | **5** |
| | | | | | | |
| **Totals** | | **13** | **8** | **4** | | **25** |

**Table 3: Student views of the impact of using the mathematics support centre upon their confidence/motivation and success (n = 25).**

## Figures

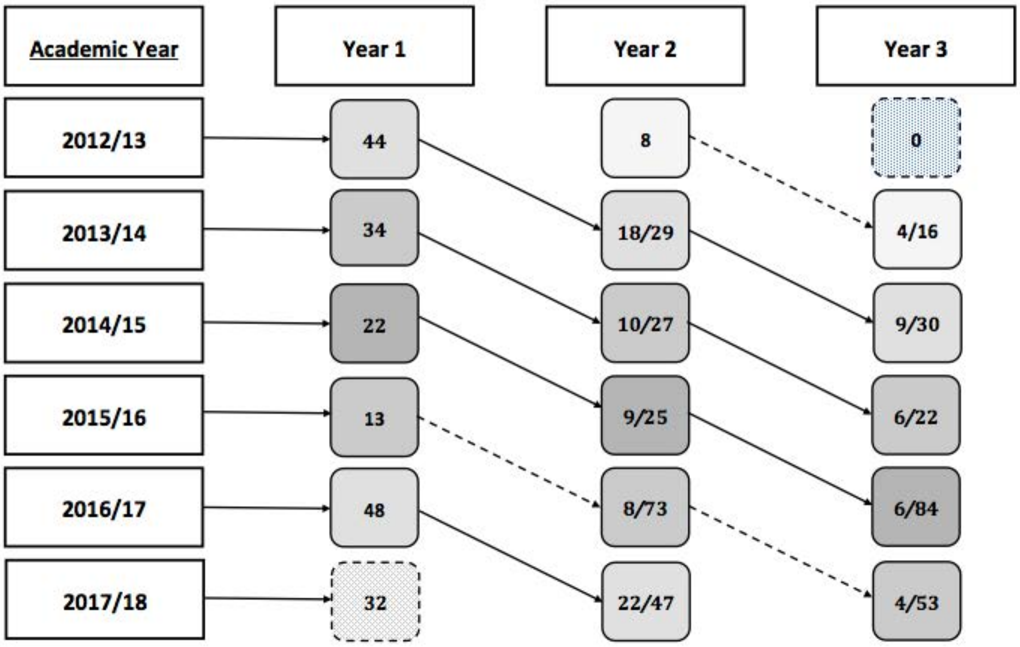


**Figure 1. The number of unique visits to the mathematics support centre by specialist mathematics students.** Where shown as a fraction, the total number of unique visitors forms the denominator; the numerator represents those unique students who also used the centre in a previous academic year and as such are return users *between* academic years.

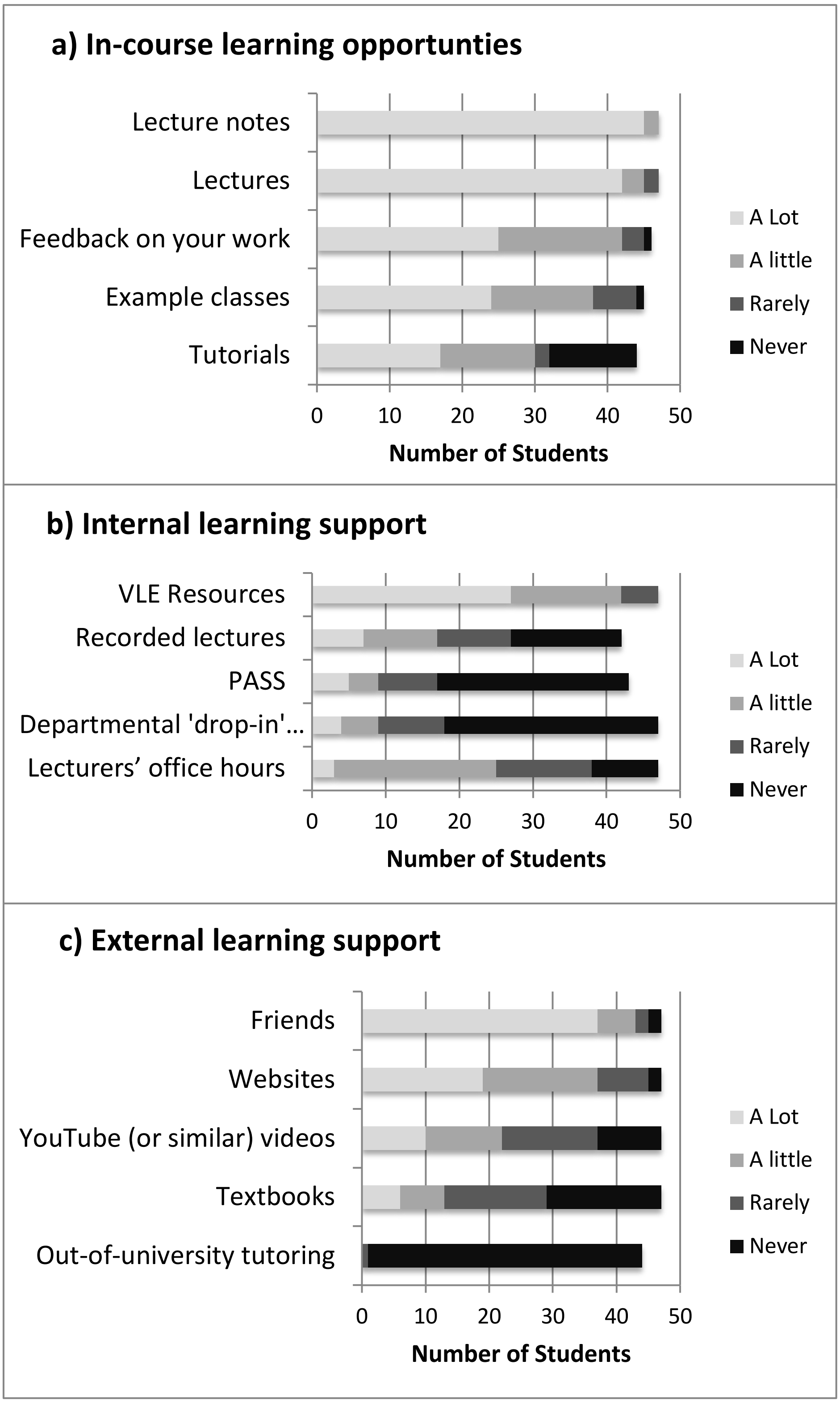


**Figure 2: What learning opportunities and resources do specialist mathematics students access to aid their learning of mathematics whilst at university? Note. N/A (not applicable) responses have been removed to aid clarity of presentation (n=47).**

# A6. Community perspectives of mathematics and statistics support in higher education: The role of the staff member

**Grove, M. J.**, Croft, A. C., Lawson, D. A. & Petrie, M. (2019). Community perspectives of mathematics and statistics support in higher education: The role of the staff member. *Teaching Mathematics and its Applications*, 38(1), pp. 43–59.

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# Community perspectives of mathematics and statistics support in higher education: the role of the staff member

Michael Grove[†,*], Tony Croft[‡], Duncan Lawson[§] and Moira Petrie[¶]
[†]*School of Mathematics, University of Birmingham, Edgbaston, Birmingham B15 2TT,*
[‡]*Mathematics Education Centre, Loughborough University, Loughborough LE11 3TU,*
[§]*Newman University, Genners Lane, Bartley Green, Birmingham B32 3NT and*
[¶]*University of Nottingham, Nottingham NG7 2RD*

[*]*Corresponding author. Email: m.j.grove@bham.ac.uk*

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**Mathematics support now forms a widely accepted and important part of the provision of higher education institutions within the UK and Ireland to assist students within their learning of mathematics and statistics, particularly as they make the transition to university study. Over the last 15 years it has seen growth as an area of scholarship, and behind this has been the role of those staff members who oversee, develop, deliver and research mathematics support within their institutions. To date, however, there has been little work that explores the roles, opportunities and recognition afforded to such individuals, but this is important if visibility for mathematics support as part of the provision and practice of higher education institutions is to continue to grow and a sustainable community of practitioners is to be established. Here we report on a survey of 51 individuals with responsibility for the day-to-day operation of the mathematics and statistics support provision within their institutions. Findings show that the majority of staff with such responsibility for the delivery of mathematics support within institutions are in permanent roles and that in many instances this forms the sole focus of their employment; there also exists an important and visible role for postgraduates in the delivery of mathematics support. Finally, there is evidence that most staff working in this area feel recognized and well supported with opportunities to develop their roles, engage with professional development and contribute to a national community of practice.**

## 1. Introduction

Mathematics and statistics support is now widely accepted by higher education institutions as a vital means of helping students develop their mathematical and statistical skills, particularly as they make the transition to university study. As this paper forms a continuation of previously described work (Grove *et al.*, 2017), we choose not to repeat here the background or rationale for mathematics support, but at its heart are those individuals whose role is to work with students to provide advice and guidance to aid their learning of mathematics and statistics.

The backgrounds of those working in mathematics and statistics support vary greatly: for example, they can be academic staff, including professors, who also undertake teaching duties as part of academic programmes; staff appointed directly to a mathematics or statistics support role, including former school teachers; or postgraduate (and, in some instances, undergraduate) students. In addition, their role may be broader than one of providing support alone—it may encompass co-ordinating or leading the mathematics support provision offered by an institution, including raising its profile and awareness of its existence amongst staff and students. Some staff have broader roles, for example in contributing to a university's widening participation initiatives.

Working in a mathematics support centre is very different from other forms of university teaching and requires a set of skills and abilities that not everyone possesses. As Croft & Grove (2016) observe: '*Providing mathematics support is not about "telling" the student the answer, but about encouraging them to identify their own mathematical problems, helping them tackle these for themselves with support and guidance, and providing suggestions and strategies for independent study. It requires individuals who are comfortable working on a one-to-one basis, who are patient, able to explain mathematical ideas in multiple ways, have excellent interpersonal skills, and are able to work with students of a range of abilities and from different disciplinary areas*.' Given the broad spectrum of levels and subjects that mathematics and statistics support encompasses (see for example Croft *et al.*, 2015), mathematics support tutors have diverse, challenging and vital student-facing roles.

While there has been much work exploring the extent and nature of mathematics and statistics support provision within higher education, there has been little that focuses upon the individuals who are essential to, and at the front-line of, providing this support. Such exploration is timely as there are a growing number of reports highlighting the increase in teaching-focused (or teaching only) academic roles and the drivers behind this trend in higher education. For example, in a UK review undertaken by Locke (2014), he concludes: '*It is a truism to emphasise the importance of staff in higher education, and especially those involved in the key functions (whatever their contractual status), to achieving future success. Yet, it is also true that the wellbeing and professionalism of these staff have largely been obscured by the recent narrow focus on the "student experience", financial issues and the economic benefits of HE*.' The growth of mathematics support over recent times is well documented (see for example Perkin *et al.*, 2012); Kyle (2010) noted the emergence of mathematics support as an area of academic study; and, Grove *et al.* (2017) identified that mathematics support is increasingly aligned as part of a wider institutional offer to support students with their learning rather than being based within academic departments. As such, there is an increasing number of staff working in mathematics and statistics support as their primary or substantive duty, and here we present the results of a 2016 survey, first described in Grove *et al.* (2017), that explores the roles, recognition and opportunities for development for these individuals within the UK.

## 2. Research methodology

The research methodology is described in full in Grove *et al.* (2017). In summary, data were obtained through an online survey targeted at those with responsibility for the day-to-day operation of the mathematics and statistics support provision within their institutions. Appropriate ethical guidelines (BERA, 2011) were followed in conducting the research: its purpose was made clear at the outset, and responses were received on an entirely 'opt-in' basis. While personal information was collected, this was to assist should further follow-up be required. Any information that might identify an individual has been anonymized in the analysis that follows, and where changes have been made to quotations this is solely for the purpose of maintaining the anonymity of responses; any such changes are shown in [square brackets]. Relevant here is that a total of 51 responses were received from staff members representing 47 higher education institutions from across the UK.

Using the results of the survey, Grove *et al.* (2017) considered the sustainability of mathematics support, at an institutional level, by applying a framework of 10 indicators developed by Grove & Pugh (2017) for analysing the sustainability of learning and teaching initiatives. Here we extend this work by applying their remaining (three) indicators to consider sustainability in the context of the individuals who dedicate their work and academic endeavours to the area of mathematics and statistics support within higher education.

## 3. The role of the individual in mathematics and statistics support

Those responding to the survey on behalf of their institutions possessed a wide range of job titles. They ranged from academic titles (including teaching fellow, lecturer, senior lecturer, reader and head of an academic department) to those where specific involvement in delivering mathematics and statistics support was clearly articulated (including maths support advisor, numeracy tutor and maths adviser). For those managing/overseeing mathematics support provision, words such as coordinator, manager, director and development officer were all referenced in their job titles. Also responding were individuals who had job titles that did not explicitly reference mathematics support, but instead indicated alignment with wider institutional initiatives (including head of academic skills, head of study skills, learning support manager, student learning advisor, learning enhancement tutor and academic skills advisor).

From job titles alone it appears that for many involved in either managing or delivering mathematics support this may not be the sole or even substantive focus of their role. Table 1 analyses the proportion of their role individuals felt was related to mathematics and statistics support. The findings here indicate that for many involved in mathematics and statistics support this forms only a component of a wider portfolio of activity. For example, 40% of respondents indicated that they spent on average two days or less working on mathematics and statistics support, and almost 20% indicated this was less than half a day per week (in one instance this was estimated to be as low as 25 minutes per week).

At an overarching level it is interesting to observe that there are a significant number of appointments (representing just over 40% of respondents) who indicated that the sole focus of their role was upon mathematics and statistics support. Interestingly, of these 'sole focus' roles, just under a third were classified as 'academic' with staff holding academic contracts; for roles where mathematics and statistics

TABLE 1. *Proportion of work time, t, dedicated to mathematics and statistics support. The 'Other' grouping includes those on 'Academic Related', 'Professional/Managerial' and 'Administrative' contract types* (n = 51)

| Percentage of role dedicated to mathematics support | $\leq$10% | $10 < t \leq 40\%$ | $40 < t \leq 70\%$ | $70 < t \leq 99\%$ | 100% | Not specified | Totals |
|---|---|---|---|---|---|---|---|
| Contract type | | | | | | | |
| Academic | 7 | 3 | 1 | 1 | 7 | 2 | 21 |
| Other | 2 | 8 | 2 | 1 | 15 | 2 | 30 |
| Totals | 9 | 11 | 3 | 2 | 22 | 4 | 51 |

support formed only a proportion of an individual's duties, just under 50% of respondents were on academic contracts. More broadly this reinforces the findings of Tolley & Mackenzie (2015) by suggesting institutions are investing strategically in their mathematics and statistics support provision and recognizes the important role that specialist individuals have in the institutional provision of mathematics and statistics support.

While Table 1 highlights the proportion of individual roles working on activities associated with mathematics and statistics support, it does not make an important distinction: that is the extent to which, during a typical week, staff spend their time (a) delivering mathematics support to learners, or (b) managing/coordinating the institutional support provision. Tables 2a and 2b explore this aspect, although a caveat is needed in relation to part-time staff—here the full-time equivalent (FTE) level was not requested, and as such, those indicating they spend, for example 10 hours, delivering support, could be spending all of their working time on this activity.

It is interesting to note that of those delivering more than 6 hours of mathematics support to learners, almost 80% were on non-academic contracts, that is those that are classified as either 'Academic Related', 'Professional/'managerial' or 'Administrative'. The type of contract is significant for a number of reasons: not only are such individuals providing a challenging form of academic tutoring with individuals who may be at high-risk of dropping out, but for those on contracts other than 'Academic', progression opportunities are typically more limited. Those on academic contracts can make a case (usually on an annual basis) for promotion based upon performance whereas those on other contract types may have to lobby to have their roles reclassified or explore opportunities elsewhere for promotion. This

TABLE 2a. *Typical hours per week spent on providing mathematics support to learners. Again the 'Other' grouping includes those on 'Academic Related', 'Professional/Managerial' and 'Administrative' contract types* (n = 51)

| Typical hours per week delivering mathematics support ➔ | Up to 3 hours | 3–6 hours | 6–10 hours | Over 10 hours | Not specified/ applicable | Totals |
|---|---|---|---|---|---|---|
| Contract type 🡻 | | | | | | |
| Academic | 13 | 2 | 3 | 3 | 0 | 21 |
| Other | 5 | 1 | 10 | 12 | 2 | 30 |
| Totals | 18 | 3 | 13 | 15 | 2 | 51 |

TABLE 2b. *Typical hours per week spent on co-ordinating, organising, promoting and managing mathematics support* (n = 51)

| Typical hours per week: delivering mathematics support ➔ | Up to 3 hours | 3–6 hours | 6–10 hours | Over 10 hours | Not specified/ applicable | Totals |
|---|---|---|---|---|---|---|
| Contract type 🡻 | | | | | | |
| Academic | 12 | 3 | 0 | 4 | 2 | 21 |
| Other | 7 | 7 | 6 | 10 | 0 | 30 |
| Totals | 19 | 10 | 6 | 14 | 2 | 51 |

latter outcome highlights a potentially significant risk for the stability and development of mathematics and statistics support within an institution if clear opportunities for staff progression and promotion are not in place.

The evidence in Tables 2a and 2b appears to suggest that academic staff have a much more limited role (at least in terms of the proportion of their time allocated), in either delivering mathematics support or managing it; almost 60% of academic staff who responded indicated their involvement in mathematics support was typically less than 3 hours per week. It may be the case that while academic staff, who are typically based within departments, do still have an involvement in mathematics support, they are involved more as 'champions' or 'advisors'. This may reflect a trend towards a more institutional-wide approach to the provision of mathematics support rather than a departmentally based model, and in doing so reinforces the findings of Tolley & Mackenzie (2015) who in their discussions with university senior management noted that '*the reported challenges were distributed across programmes of study in a wide range of subjects*'.

The changing contractual backgrounds of those involved in mathematics support represent a potentially wider issue. Over the last 10–15 years there has been a growing visibility of mathematics and statistics support within the body of scholarly works. For example, in their 2012 survey, Perkin *et al.* (2012) found '*there were 27 universities which have external publications relating to their mathematics support*', and in the same year the extensive publication of Matthews *et al.* (2012) made available reviews and syntheses of published research (having considered almost 80 scholarly works) into how mathematics support professionals collect and analyse data to evidence usage of the support and the impact of the support on students, staff and the institution. Academic staff have been one of the key contributors to this body of scholarly knowledge, and this is unsurprising since it is typically those on this contract type that have the allocated time, flexibility and indeed expectation, that they will pursue research and scholarly endeavours as part of their roles. With evidence that there appears to be a reduced involvement of academic staff with mathematics support, and that the delivery and management of mathematics support is taking place by those typically on non-academic contracts, there are implications as to whether this community-wide sharing of scholarly knowledge will continue at the same pace and to the same extent.

While this survey was targeted at those with responsibility for the day-to-day operation of the mathematics and statistics support provision within their institutions, it is recognized that there is another cadre of staff whose role focuses upon the delivery of mathematics support to learners. The involvement of these individuals as tutors, who we will discuss further in Section 6, may present a further perspective on the range of contract types possessed by those working in mathematics and statistics support within higher education.

## 4. Responsive and reactive provision

Mathematics and statistics support has not remained static and key to this has been the role of staff members working in this area. As noted by Kyle (2010) '*colleagues have moved on to gather data on the way students use such resources and look for optimal strategies for the delivery of this support'*. The scholarly approach that has been adopted by many of those delivering mathematics support has meant that the provision itself has evolved, resulting in a broader range of students being targeted and the exploration of new and dynamic ways of engaging with learners throughout an institution and throughout the academic cycle.

In the survey respondents were asked to articulate whether their mathematics and statistics support provision was open to all students within their institution or whether it was restricted to certain disciplines or years. Overwhelmingly (37 responses) it was the case that mathematics and statistics support was indicated as being available to all students within the institution. There were two instances noted (both large research intensive universities) whereby students from the later years of mathematics degrees were also attending and support was offered, even though this was not the primary mission of centres:

> Officially we exist for first and foundation year students only, and mainly for students not studying for a degree in maths. In practice though our drop-ins are attended by students from all years and many disciplines, including mathematics, and we don't turn any of these people away without attempting to help them.

And in another institution such specialist mathematics students were able to engage, but other cohorts were given priority:

> . . .although mathematics students higher than first year undergrad are permitted to use the service, they have lower priority than other students.

This clearly highlights a broadening of the role of mathematics support, and the related challenges for those who provide it. In its earliest stage (Hawkes & Savage, 2000), mathematics support was established to support those students in the disciplines of mathematics, engineering and physics with their learning of mathematics as they made the transition to university study. As such, the provision addressed what might be termed 'basic introductory techniques' such as those typically expected at foundation or first-year. Here there exists evidence that the extension of this remit can put additional demands upon mathematics support services.

Seven institutions limited their support to certain disciplines, including one large research-intensive institution, who noted that their provision was unavailable to specialist mathematics students. In others, there were instances where postgraduate research students were not encouraged to use the available support:

> PGR students are not encouraged to use the service.

But in others, it is targeted at such students:

> . . .the statistics workshops are offered through the graduate school, and are only open to postgraduate students.

In addition to the diversity of the target cohorts, it is also particularly interesting to note how there is now increasing usage of what might be termed 'hybrid' models of mathematics and statistics support in order to maximize engagement from particular cohorts of learner. For example in one institution where there exists both a departmental and centralized mathematics support service:

> . . .many more biosciences students use our departmental service than go to the centralised alternative.

There also appears to be an increasingly common feature of mathematics support whereby in addition to provision that is available to any student, specialist support sessions are offered for particular cohorts that are linked to the work of their home department:

> . . .targeted provision tailored at a school, programme or module level. This takes the form of embedded sessions within timetabled lectures or seminars or sessions which are promoted to particular cohorts taking place directly after lecture.
>
> Some colleges/departments also offer specific support just for their students. . .

This forms an interesting development. Mathematics support was originally, and almost primarily, structured around a model whereby an individual student could 'drop-in' to a centre or location and seek advice and guidance from a tutor at a time to suit them to aid their mathematical learning; one of the key benefits of this approach recognized by students is the ability to engage in individual mathematical dialogue with a tutor about their learning. Here there is evidence of a move away from individual support to the exploration of support within the context of a discipline or programme for a particular cohort. There are advantages including greater efficiencies achieved by targeting students together; the embedding of mathematics support within disciplinary curricula; and increased visibility and attractiveness to students. Such a move represents an evolution of the models of mathematics support and indicates how mathematics support is responding to disciplinary needs within the context of institutional provision, but as a consequence means that it is no longer necessarily focused upon the individual which can have negative impacts for some learners. Numerous studies highlight the value to students of personalized and one-to-one support available in drop-in centres but not available in a tutorial or lecture environment (Lawson *et al.*, 2003). Moreover, other studies report that students believe many lectures are fast, difficult to follow and allow little—if any—time for discussion. Further, the fact that students might feel exposed to raise questions during tutorial sessions means that tutorials are considered as risky places, (Solomon *et al.*, 2010). Drop-in centres can overcome these difficulties.

By analysing the free text responses, just over 20% of the institutions who responded to the survey indicated that they used approaches to providing mathematics support (excluding online means such as the provision of resources) that were in addition to the traditional drop-in centre model, to deliver their mathematics and statistics support provision. While still a vital part of the provision, mathematics support is clearly diversifying beyond the drop-in centre model alone.

## 5. Reward and recognition within mathematics support

The findings from the survey indicate that much of the delivery of mathematics support takes place by staff on contracts other than those classified as 'Academic' (Table 2a). Table 3 shows that although 11 of the 51 responses came from the research-intensive 'Russell Group' universities, they had the lowest proportion of those overseeing mathematics and statistics support who were on academic contracts (just two individuals). In fact, 9 of the 13 responses from the University Alliance (a group formed of universities with a particular focus on links with business and industry and applied research) were on academic contracts, and in the million+ (an association for modern universities) this was four from seven.

Amongst the Unaligned Universities, 'Academic Related' contracts were the most widely used for those overseeing mathematics support whereas amongst the Russell Group institutions the use of

TABLE 3. *Contract type by institutional categorization (*n = 51*)*

| Institutional grouping ➔ | Russell Group | University Alliance | Million+ | Unaligned | Totals |
|---|---|---|---|---|---|
| Contract type 🡻 | | | | | |
| Academic | 2 | 9 | 4 | 6 | 21 |
| Academic Related | 4 | 1 | 1 | 8 | 14 |
| Professional/managerial | 5 | 2 | 2 | 1 | 10 |
| Administrative | 0 | 1 | 0 | 5 | 6 |
| Totals | 11 | 13 | 7 | 20 | 51 |

‘Professional/Managerial’ contracts was the most common (5 out of 11 individuals). Up until recently, a number of the universities now classified as ‘Unaligned’ were members of another grouping, the ‘1994 Group’. The 1994 Group disbanded in 2013, but represented a coalition of smaller research-intensive universities, thus it appears that research-intensive universities (the Russell Group and 1994 Group) are less likely to have those overseeing mathematics support employed on academic contracts.

Overall it seems the case that in the majority of institutions, mathematics support, an academic service, is not overseen or co-ordinated by those staff on academic contracts, but rather by those on the myriad of non-academic contracts specified in Table 3.

Participants were asked whether they felt that, as individuals, they had received recognition for their work; examples of possible types of recognition were provided to inform responses and these included include promotion, awards and conference invitations. Of respondents (Table 4), it was the case that 22 individuals felt they had received some form of recognition for their work and 29 felt they had not. It was the case here that similar proportions of academic and academic related staff felt they had received recognition for their work. For those on academic contracts, examples of recognition included: international awards, student and institutional awards, National Teaching Fellowships, **sigma** prizes, and amongst the 11 respondents, four explicitly referenced their involvement in mathematics support as contributing to promotion success. For those on academic related contracts, a number of references (five) were made to institutional awards associated with the student experience, including those nominated by students directly, but most significantly not one reference here was made to promotion. For those on professional/management contracts, recognition again included an example of student awards, being invited to speak at events and conferences, and professional fellowships.

The data were further interrogated (Tables 5a and 5b) to explore if recognition was in any way related to the length of time individuals had worked in mathematics support, either within their current institution or elsewhere, or whether this might be linked to clear governance and regular reporting processes being in place for mathematics support within the institution, for example a steering or advisory group or written reports to senior management. This latter aspect was felt to be important because as one survey respondent commented in relation to them receiving recognition for their work:

> Not really, our senior management are not particularly aux [sic] fait with what maths support is about.

Although not universally true, for those receiving recognition for their work in mathematics and statistics support, it does appear that this is linked to working in this area for a period of 5 years or more, and perhaps reflects the time period needed in order to collect evidence to support a submitted case for recognition or ‘catch the eye’ to be nominated for recognition. For those who had received recognition

TABLE 4. *Individual recognition for mathematics support activities (*n = 51*)*

| Contract type ↓ | Within institution | Nationally | Both institutionally & nationally | Recognition | No recognition |
|---|---|---|---|---|---|
| Academic | 4 | 1 | 5 | 10 | 11 |
| Academic related | 6 | 1 | | 7 | 7 |
| Professional/managerial | 2 | 1 | 1 | 4 | 6 |
| Administrative | 1 | | | 1 | 5 |
| Totals | 13 | 3 | 6 | 22 | 29 |

Table 5a. *Individual recognition for mathematics support activities (*n = 51*)*

| Length of time working in mathematics support ➔ | Less than 5 years | More than 5 years | Totals |
|---|---|---|---|
| Recognition ⬇ | 6 | 16 | 22 |
| No recognition | 18 | 11 | 29 |
| Totals | 23 | 27 | 51 |

Table 5b. *Individual recognition for mathematics support activities (*n = 51*)*

| Are governance/reporting arrangements in place for mathematics support? ➔ | Yes | No | Totals |
|---|---|---|---|
| Recognition | 16 | 6 | 22 |
| No recognition | 8 | 21 | 29 |
| Totals | 24 | 27 | 51 |

despite only being in the role for less than five years, this was typically related to institutional teaching awards and prizes, many of which were identified as being nominated by students.

In exploring whether recognition was in any way related to governance and reporting processes being in place (Table 5b), there is a clear trend: where governance and reporting arrangements were in place for mathematics support, two-thirds of staff had received recognition for their work; where such arrangements were not in place recognition fell to just over 20%. Such a finding is likely to be linked not only to the visibility of mathematics support amongst senior management, but also to the fact that reporting is likely to involve the provision of data and evidence demonstrating the impact of mathematics support upon both individuals and cohorts of learners. As such, there are personal benefits for those working in mathematics support to ensure clear and regular reporting arrangements to senior management are in place, and also for institutions themselves where mathematics support can provide vital evidence of their commitment to enhancing student learning and success (Tolley & Mackenzie, 2015).

In their responses, a number of individuals commented that recognition for their work came from being able to engage with national (and international) activities related to mathematics and statistics support. Opportunities for recognition are also afforded by being able to develop provision within institutions, and through the collection of evidence and data that individuals can then use to either develop their roles or in support of any recognition-based promotions case. In order to do this, staff need to feel that they have a level of autonomy, are supported by their line-managers to engage in national activities and are able to participate in professional development opportunities. Table 6 explores this aspect of the survey responses.

Overall staff working in mathematics and statistics support feel that they have a high level of autonomy, and this applies regardless of contract type or length of time within their current role. Perhaps most surprising are the responses for administrative staff who indicate high levels of autonomy where it might instead be expected that there would be a greater level of management supervision/direction of their activities. This may reflect the fact that such individuals are undertaking roles that extend beyond the scope of what might reasonably be classified as 'administrative'. Interestingly it was academic staff who, on the whole, felt they were less supported to engage with national activities associated with mathematics

Table 6. *Extent to which management supports staff. Note, scores are grouped into 'supported (S)' (scores* 4 *and* 5*), 'Neutral (N)' (score* 3*) and 'unsupported (U)' (scores* 1 *and* 2*) (*n = 51*)*

| | Autonomy | | | Professional development | | | National engagement | | |
|---|---|---|---|---|---|---|---|---|---|
| | S | N | U | S | N | U | S | N | U |
| Academic | 12 | 6 | 3 | 13 | 3 | 5 | 12 | 2 | 7 |
| Academic related | 7 | 3 | 4 | 11 | 1 | 2 | 10 | 4 | |
| Professional/managerial | 8 | 2 | | 8 | 1 | 1 | 8 | 2 | |
| Administrative | 5 | | 1 | 4 | 1 | 1 | 4 | 1 | 1 |
| Totals | 32 | 11 | 8 | 36 | 6 | 9 | 34 | 9 | 8 |

and statistics support. While this may correlate with the fact that, for this group, mathematics and statistics support was highlighted as only a small component (typically less than 0.1 FTE) of their wider institutional role, it might also be related to who they are comparing themselves with. For example, academic staff working in mathematics support might perceive their colleagues working in disciplinary research have much more autonomy over their academic endeavours; similarly, for administrative staff working in mathematics support, they may perceive themselves to have far more autonomy in their activities than their colleagues working in more 'traditional' institutional administrative roles.

In other groups, staff felt they were well supported to engage with national activities, which is a positive development. Previously there were externally funded networks (for example those of the Higher Education Academy Subject Centre Network, the National HE STEM Programme and most recently the **sigma** Network) that sought to encourage such collaborations through workshops, events and small-scale funding, however funding for these networks has now ceased. Within England (and possibly other nations), the move towards greater scrutiny of higher education institutions' commitment to enhancing teaching excellence continues (DfE, 2017). This creates an incentive within institutions for their members of staff to engage more widely in order to identify effective practices and approaches used elsewhere that they may in turn adopt and adapt in order to enhance their own institutional offer.

This was further validated when the views of respondents in relation to the extent to which they felt supported to engage in professional development activities were considered; overall staff felt supported to engage with such opportunities. Interestingly where there was less perceived support, this appeared to be from staff who have been involved in mathematics support for the greatest length of time, even though such staff generally indicated they had a high level of autonomy within their roles. This may potentially flag a much wider issue, that is one of continuing professional development vs. initial professional development. It is possibly the case that staff who have been in their roles for a longer period receive less attention (other than perhaps an annual development review), or that the provision that is available to them is not sufficiently focused in order to meet their development needs. This in itself aligns with a broader issue observed in UK higher education, particularly for 'teaching-only' or 'teaching-focused staff', as to how such individuals can develop within their roles (Locke, 2014).

## 6. Who else delivers mathematics support?

From the results of the survey it is evident that mathematics support is extensively offered within institutions, that is, provision is available for more than 10 hours per week in the majority of cases (Grove *et al.*, 2017). Yet Table 2 highlights that for a number of institutions the staff members responding

TABLE 7. *Those delivering mathematics and statistics support within institutions. Note, respondents were able to tick all that apply*

| | |
|---|---|
| Yourself | 32 |
| Academic colleagues from a single discipline | 15 |
| Academic colleagues from a range of disciplines | 1 |
| Academic related colleagues | 9 |
| Postgraduate tutors | 25 |
| Undergraduate tutors | 6 |
| Visiting/sessional/hourly paid tutors | 11 |
| Other | 4 |

to this survey would not, on their own, be able to deliver such a quota of support, and further, issues were noted by some respondents in relation to the capacity of their institutions to provide specialist statistics support:

> Statistics support is offered during a specific drop-in session (due to a lack of statistics tutors) and appointments are available upon request.

This gives rise to a valid question—who is involved in the delivery of mathematics and statistics support to learners within institutions? The results from the survey are shown within Table 7.

Table 1 shows that 22 out of the 51 survey respondents have mathematics and statistics support as the only component of their role, and there were instances of a small number of (either full-time or part-time) staff employed to solely provide this support:

> There are 2 of us who are part time maths tutors. . ..

> There are two of us employed as Maths & Stats tutors. This is our primary role.

In other cases, academic staff from departments had a key role, although in three instances where this was the case, mathematics and statistics support was restricted to students from particular disciplines. What is most striking from the survey is that there were 19 individuals who were involved in overseeing or managing mathematics support activity within their institutions but who had no role in delivering provision to learners; conversely there were five individuals who indicated that it was only they themselves who provided this support, and in four of these instances, the mathematics support was available to all students within their institution.

A prominent feature evident from the survey is the reinforcement of the key role that postgraduate students (almost 50% of institutions) play in the provision of institutional mathematics support, and the evidence that in a limited number of cases (12% of institutions) undergraduate students also have a role:

> One academic, from a rota of 5 lecturers in [removed] with particular expertise in quantitative analysis in their research and core teaching, leads the weekly drop-in. This is supported by one PhD student at busy times of year.

> Mostly staffed by main grade lecturers from the maths dept. and maths/stats PG students (MSc and PhD)

[removed] is staffed by the Engineering Maths lecturers at all times. If it is very busy we may have additional help from the engineering peer tutors - 3rd and 4th year engineering students who help in tutorials.

Delivering mathematics and statistics support is a challenging form of teaching and as such, training for those new to working in this environment is vital (Croft & Grove, 2016). With many institutions using postgraduates, and in several cases undergraduates, to provide support, respondents were asked whether their institutions provided some form of training to those new to working in this environment. Of the 48 responses received to this question, 25 said they provided some form of training versus 23 who said they did not. For those who did not, the reasons given indicated it was due to delivery being by a small team that had not yet grown, or because '*we only use academics and experienced peer tutors*'. However, there was recognition within these institutions that training would be considered if needed in the future:

Not yet. We are a very small team but this is something that we would be interested in as we grow.

We would but we haven't needed to as all our maths support staff have either worked here for a long time or have provided maths support at other institutions.

But even where engagement with such training would be supported, tutors have not always taken this up, which may indicate training is not always compulsory:

I have encouraged the tutors to join SIGMA and flag up any training they spot. I would support them doing this, but so far they have not taken it up.

For those that offered training to new tutors, a common feature (seven responses) was the engagement with the provision that **sigma** has offered (see Croft & Grove, 2016) over the last 5 or 6 years to support postgraduates, in particular, involved in mathematics and statistics support:

Sigma supported training is required of all maths support tutors.

Some institutions chose to complement this with their own provision, and examples were noted of good practice in ongoing mentoring and training support:

It is training based around the sigma guide, but we also run a mentoring scheme (informal) where we pair tutors to help people develop experience. Former tutors, who are now staff members also help out with this.

Training is provided via Sigma Network, induction and on the job training using real examples of students' problems.

Others offer their own institutional training and mentoring programme, but for some, this appears to only consist of a short or informal briefing:

A brief and simple induction.

Very short briefing/debrief session only.

On the basis that postgraduate tutors are selected and appropriately trained, their involvement in mathematics and statistics support has benefits (Croft & Grove, 2016): having been recent graduates themselves, perhaps even within the same institution, postgraduates should not only have empathy with the students who attend, but may also have familiarity with the aspects of the mathematical curriculum with which a certain cohort may struggle. As individuals, they develop a range of transferable skills that will place them at an advantage when seeking employment or an academic career. Further, they may also potentially represent the 'next generation' of staff members who choose to develop a career in mathematics and statistics support.

## 7. Sustainability

Grove *et al.* (2017) noted the sustainability of the community-wide approach to mathematics and statistics support developed over the last 20 years as existing in two parts: the practice and provision of mathematics support as led by higher education institutions, and the scholarship of mathematics support as led by the individuals who work within it. While this earlier work considered the institutional aspects of sustainability by considering 7 of Grove & Pugh's (2017) 10 indicators, here we extend this analysis by exploring their remaining three indicators, relating to sustainability through the influences, activities and scholarship of the individuals involved in mathematics and statistics support.

### *7.1 Dissemination and developing a community identity*

Dissemination forms an important part of the scholarship of teaching and learning. Further, it is very much linked to 'having a story to tell' and so aligns with the needs to 'evaluate' and 'research' one's own practices and their impacts and contributes to engaging individuals as part of a wider scholarly community (hence here we choose to consider these two indicators together). Through the survey (Table 6) it was evident that many respondents felt they had autonomy to engage with the national activities associated with mathematics support, many of which have been established through the work of **sigma** (Croft *et al.*, 2015). This has been very much borne out by the engagement of individuals with **sigma** events and workshops (see for example Sigma (2015)).

There is the existence of an active and visible mathematics support community which has been fostered through the support of **sigma**. Respondents (Table 6) reported they had a high level of autonomy to engage with national activities, and the value offered by the existence of such a community has been noted by senior management themselves:

> The overwhelming majority of those interviewed recognised the value of some level of national collaboration in respect of mathematics and statistics support. At the most basic level, this provides for sharing of resources and experiences to help avoid "re-inventing the wheel".
> (Tolley & Mackenzie, 2015)

While financial support for **sigma** ceased at the end of July 2016, substantial effort has gone into establishing a sustainable network building upon the activities of the last 10 years. A national steering committee is now overseeing the future work of this network, and contains wide representation from across the higher education sector. This model for a practitioner network has proved particularly successful in both Ireland (including Northern Ireland) and Scotland with the active and visible Irish Mathematics Learning Support Network (Mac an Bhaird *et al.*, 2011) and the Scottish Mathematics Support Network (Ahmed *et al.*, 2011), members from which have been particularly active in working with colleagues on mathematics and statistics support activities in England and Wales.

In addition to disseminating through conferences and events, which in themselves are key mechanisms by which an individual can build collaborations and become part of a network, disseminating through publication is key to helping an individual develop their academic identity. Most recently, in the restarted journal *MSOR Connections*, originally published in the UK by the Higher Education Academy Maths, Stats & OR Network, of the 25 papers and case studies published in 2016, 10 were focused upon mathematics and statistics support. It is also interesting to note that of these 10 papers, five were collaborative between institutions.

For many years those working in mathematics support have collaborated on joint activities and through sharing their ideas; increasingly these individuals are making available the outcomes of their scholarly endeavours to enhance the collective literature-base for mathematics and statistics support. The evidence collected to date demonstrates that while the visibility of mathematics support continues to grow, there remains a need for caution. While staff indicate they feel they have a level autonomy to develop their role, many working in mathematics and statistics support are on contract types other than those classified as ‘Academic’, and as such, do not have the contractual arrangement that allows them the same level of freedom as academic colleagues to explore their own research and scholarly interests.

### *7.2 Professional development and recognition*

For those working in mathematics and statistics support and responding to this survey, just over 40% indicated they had received some form of recognition for their work, over 60% felt they had autonomy within their role and almost two-thirds felt supported to engage with national activities in mathematics and statistics support. The ability to develop one’s role as well as to engage with national communities of practice are both important for achieving recognition and visibility for one’s work. Similarly feeling supported to undertake some form of professional development activity was indicated by over 70% of respondents; however, for this to happen, it is important that appropriate development opportunities are available. These opportunities do not necessarily need to be ‘formal’ or ‘accredited’; equally important are the development opportunities where individuals can come together to share ideas, discuss their work and develop their own collaborations.

Delivering mathematics support can also have an important role in developing postgraduate tutors who may be seeking to pursue a future academic role by providing valuable teaching and student support experience. Such individuals need to be appropriately trained and subsequently mentored. Through **sigma** a national and collaborative model for training postgraduate students has been established (Croft & Grove, 2016), and it is evident from this survey that postgraduates have a crucial role in the delivery of mathematics and statistics support provision. Further, this model of postgraduate support developed by **sigma** has been adopted and adapted within Ireland for use across all institutions who offer mathematics and statistics support (Fitzmaurice *et al*., 2016).

More broadly, the evidence indicates there is increasing recognition being given for mathematics support, and students, whose nomination awards were cited as a key form of recognition by those working in mathematics support, are likely to have a greater say in articulating what they regard as effective teaching practices in the future (DfE, 2017). In this regard, and in particular through the ‘student voice’ there are further positive signs for the sustainability and visibility of mathematics support within UK higher education.

## 8. Conclusions

Grove *et al.* (2017), which presented the results from this survey related to the (infra)structural aspects of mathematics and statistics support provision, validated the findings of Tolley & Mackenzie (2015) by showing that mathematics support is not only widely available to students from a range of disciplines but also that it is being increasing aligned with other institutional student-focused services, and that mechanisms are increasingly in place for universities to utilize their findings and experiences from offering mathematics support to feed into main-stream teaching and learning. There is further evidence of the strategic approach to the delivery of mathematics and statistics support as the survey presents evidence of those working within mathematics support using multiple delivery models to target and engage identified cohorts of learner.

Historically mathematics support has primarily focused upon assisting students from disciplines other than mathematics in developing their knowledge and skills. There is evidence that specialist mathematics students, including those in their later years of study, are now availing themselves of mathematics support. In addition, there is also evidence of both staff members and postgraduate students also accessing mathematics support, particularly in relation to statistics. While supporting such students is in no way a universal feature of the provision surveyed here, this clearly is an interesting extension to the role and remit of mathematics and statistics support as originally envisaged which needs careful consideration and management. It poses new challenges relating to understanding the motivations of such students for accessing the provision, managing their expectations once they arrive, and in providing support for what might be quite specialized and technical queries. While it may be the case that these students are struggling, it may also be the case that these students are already doing very well but are seeking to improve even further.

Tutors, be they members of staff or postgraduate students, are vital to the success of mathematics support. In considering the conclusions from our survey, it is important to do so within the context of the conclusions from Locke (2014) who explored the changing nature of academic careers. In his conclusion, Locke noted a series of issues requiring attention. These may be summarized as: supporting early career academics; '*the shift to teaching-only contracts and roles, especially where this reduces status and prospects, and restricts the capacity of those who wish to pursue broader academic roles (particularly research)*'; helping develop new leaders in teaching; supporting individuals to develop their scholarship, expertise and skills through continued professional development; and, '*enhancing professionalism in teaching and learning in higher education and the research and scholarship that underpins this*.'

The staffing associated with mathematics support offers further indication that within institutions mathematics support is becoming an increasingly important student-focused service. Just over 40% of respondents indicated that their role was solely focused upon mathematics and statistics support, either delivery or management (or both), but further the data show that almost 90% of the staff who responded were in permanent roles. Coupled with this trend, however, is evidence of the important role that postgraduate students play in the provision of mathematics and statistics support with almost 50% of centres using postgraduates as part of their delivery approach. Yet while there is widespread recognition of the importance of such training and mentoring, and a willingness to access the national models of support and training currently available, not all institutions currently have training and mentoring provision in place for those new to tutoring in mathematics support.

While there are many positives for those working in mathematics and statistics support, particularly in the level of autonomy staff feel they have within their roles, the ability to engage with professional development provision, and the opportunities to contribute to a national community of practice, there are areas that require further consideration. For example, our survey found that where there was less perceived support to engage in professional development activities, this was from staff who had been working in mathematics and statistics support for the longest time. It must be noted that this may not be the fault of institutions, but instead may reflect a lack of suitable (subject-specific) development opportunities with which such staff can engage.

Staff working in mathematics support have been particularly active at adding a scholarship dimension to their roles. As noted first by Kyle (2010), there are now an increasing number of academic works relating to mathematics and statistics support being published as part of the learning and teaching literature. With staff in mathematics and statistics support commenting in general that they feel they have autonomy in their roles, many more staff might begin, or further develop, their scholarly practices if given the support, opportunities and (contractual) flexibility to do so. While there have been developments in this area which have been supported by **sigma** (see for example Grove & Overton, 2013), this is an area where a community-wide approach is needed.

Finally, our analysis of the potential for sustainability of mathematics and statistics support is once again very promising. It does indeed show that national practices in mathematics and statistics support are visible and highly likely to continue into the future, both through the provision of higher education institutions, and the practices of those individuals who work in this vital area of higher education activity.

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**Michael Grove** is a Reader in STEM Education within the School of Mathematics at the University of Birmingham. He is a National Teaching Fellow and was Associate Director of the **sigma** Network for Mathematics and Statistics Support between 2013 and 2016.

**Tony Croft** is Professor of Mathematics Education at Loughborough University and has developed mathematics support there for many years. He was a Director of the **sigma** Network for Mathematics and Statistics Support from its inception in 2005 up until the end of its most recent HEFCE funding in 2016. He was a Director of **math**centre, the UK's virtual mathematics learning support centre, and was awarded a National Teaching Fellowship in 2008. He was awarded the IMA Gold Medal 2016 for his outstanding contribution to mathematics.

**Duncan Lawson** is Pro Vice Chancellor (Formative Education) at Newman University, having previously been the founding Director of **sigma** at Coventry University where he worked in mathematics support for over 20 years. He was awarded a National Teaching Fellowship in 2005 and was also awarded the IMA Gold Medal 2016 for his outstanding contribution to mathematics.

**Moira Petrie** is currently Network Plus Manager: Industrial Systems in the Digital Age at the University of Nottingham. Prior to her most recent role she was project manager for the **sigma** Network for Mathematics and Statistics Support.

# A7. Learning to be a postgraduate tutor in a mathematics support centre

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# Learning to Be a Postgraduate Tutor in a Mathematics Support Centre

Michael Grove[1] · Tony Croft[2]

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## Abstract

The study reported here investigates the role, experiences and aspirations of a community of mathematics postgraduates as they learn to tutor in a mathematics support centre in a research-intensive university. This is achieved through in-depth interviews with nine postgraduate tutors all of whom had experience working in the centre. The data is analysed through the lens of communities of practice and presented through the voices of the postgraduates themselves. It sheds light on their personal trajectories as 'newcomers' to the peculiarities of tutoring within a mathematics support centre, and the ways in which they learn from, support and cooperate with each other in their common endeavour. As the postgraduates progress through their three or four years working in the centre the data reveals a growing confidence and, for some, a strong willingness to nurture and encourage their younger colleagues. Some of the 'old timers' go on to assist in the recruitment of new tutors and demonstrate insights into the ways their experience as tutors in the support centre will inform and influence their own future careers as academics. In particular, our work highlights the ways in which tutoring in the centre contributes to their own mathematical learning and personal development. The work is driven by a need to better understand the practices of postgraduate tutors in the growing field of university mathematics support and a desire to improve these. We consider how what we have learned can be put to use both in mathematics support centres and in university mathematics education more generally. By doing so we contribute to the solution of a widely reported 'mathematics problem' in higher education. At the same time this work strengthens what has been described as a 'fragile' relationship between mathematicians and educational researchers, bridging the gap between theoretical understanding and practice in a research-intensive university mathematics department.

**Keywords** Mathematics support · Postgraduate tutors · Community of practice

✉ Michael Grove
m.j.grove@bham.ac.uk

[1] School of Mathematics, University of Birmingham, Birmingham B15 2TT, UK

[2] Mathematics Education Centre, Loughborough University, Loughborough LE11 3TU, UK

## Introduction and Background

University level mathematics support has been defined by Lawson, Croft and Halpin (2003, p9) as "a facility offered to students (not necessarily of mathematics) which is in addition to their regular programme of teaching, lectures, tutorials, seminars, problems classes, personal tutorials, etc.". The most common model that is used is a 'drop-in' centre which offers one-to-one support to students who drop-in at a time of their choosing. The establishment of such centres represents one way in which many UK universities have responded to the challenges mathematics educators face at the school/university transition. This so-called 'mathematics problem' can be summarised as the under-preparedness of new undergraduates (primarily in non-mathematical sciences disciplines) for the mathematical and/or statistical demands of their degree programme (Hawkes and Savage 2000). These challenges have been articulated in the UK's Post-14 Mathematics Inquiry's conclusion that "higher education has little option but to accommodate to the students emerging from the current GCE (General Certificate of Education, i.e. pre-university schooling) process" (Smith 2004, p95). More widely, in both Ireland (O'Sullivan et al. 2014) and Australia (MacGillivray and Wilson 2008) mathematics support centres are also a recognized means of responding to difficulties in learning mathematics encountered by students when starting their university studies.

The case for mathematics support centres has already been made extensively (e.g. Tolley and Mackenzie 2015). While their greatest benefit is the availability of focused one-to-one support as an immediate response to specific problems, student users also comment on the importance of the atmosphere and learning environment, an increase in student control and lack of time pressure, and the informality and psychological security of centres (Lawson et al. 2001). Solomon et al. (2010) describe their role in the encouragement of undergraduate learning communities, particularly for mathematics specialists in the later years of a degree, and Solomon and Croft (2016) in engendering positive attitudes to university study of mathematics and overcoming widely-reported alienation from the subject even amongst those who choose to study it at university.

Within many mathematics support centres postgraduates working as tutors are at the frontline in providing support to undergraduates with their learning of mathematics. Their role consists of working with students, typically on a one-to-one basis, to try and understand their mathematical problems and then offering advice, guidance, motivation and support to help the student successfully work through these issues. While the impact of mathematics support upon institutions, and the students themselves, is becoming increasingly understood (Grove et al. 2019a; O'Sullivan et al. 2014), there has been little work to date exploring the lived experiences of those individuals who provide this support although some have commented upon the role of the postgraduate tutor in this process (e.g. Foster 2005).

Our goal here is to investigate postgraduate tutors' perceptions of their role in a mathematics support centre and report on ways that they say they have developed and learned through the experience. We want to understand their day-to-day experiences in the centre and how they react to contingencies that arise. We set out to explore the extent to which these tutors share a common purpose and support each other in their endeavours. In the research reported here, data from the perspective of the postgraduate tutors, collected through nine in-depth interviews, is used to explore the nature of their working in mathematics support and the crucial role of the community of which they are part. We aim to achieve this goal through an analysis that draws upon the theoretical perspectives of communities of practice.

The authors have been at the forefront of establishing mathematics support centres throughout the UK and of developing and delivering training for those who work in them (Croft and Grove 2016). They have been instrumental in the design of higher education policy in respect of mathematics support centres (e.g. Mackenzie et al. 2016). The research reported in this paper combines a drive for understanding the community of postgraduate mathematics support tutors - framed using existing theoretical understanding of communities of practice - with a desire to improve the practice of those involved. This work can be regarded as 'use-inspired basic research', located in the so-called Pasteur quadrant (Stokes 1997) and as bridging the gap between rigorous theory and practice-based evidence. As such it makes a significant contribution to strengthening of what Nardi and Iannone (2004, p401) refer to as "the fragile, yet crucial relationship between mathematicians and researchers in mathematics education".

We consider how this understanding can be put to use both in mathematics support centres and in university mathematics education more generally and by doing so contribute to the solution of the previously noted and widely reported 'mathematics problem' in higher education.

## Context of the Study

The research took place in a research-intensive English university. The University has a drop-in mathematics support centre, established in 2012, and based in the University Library. As is common practice the centre is equipped with student workspace, whiteboards and access to computing facilities. It opens for six hours daily during term time and students from any discipline and at any level of study can drop in to ask for specific help with mathematical or statistical problems arising in any of their courses. While the University Library manages the centre (within a wider student study skills support operation) academic oversight (including the recruitment and training of tutors, responding to tutor queries and concerns, ongoing liaison with the tutors, and the monitoring of the quality of the support) is provided by the University's School of Mathematics by a named member of the academic staff, herein referred to as the 'centre manager'. A particular characteristic of the centre, and one that distinguishes it from many university support centres, is that its tutors are exclusively recruited from the School's large (approximately 60 in 2017/2018) postgraduate population. Tutors always work in pairs for typically three hours at a time and receive hourly payment. These tutors are drawn from all three or four years of their postgraduate lifetimes, with first years being relatively new to tutoring, and others having worked in the centre for between two and four years. Within the School, approximately 55% of postgraduates undertake their research in pure mathematics and 35% research in applied topics; the remainder work in management mathematics and statistics. As we shall see, this split is not reflected in the proportions of each group that work as tutors and the interviews will reveal how this situation is mitigated. There is a strong gender bias amongst the School's postgraduate population (approximately 80% are male) and this is reflected in the number of male/female tutors who work in the centre.

All new postgraduates involved in teaching within the School receive a compulsory mathematics-specific one-day training session as described in Grove et al. (2006). While broader than the training model described in Croft and Grove (2016), which is widely used for those working in mathematics support, it contains elements highly relevant to working in a support centre, for example presenting and communicating mathematics and problem solving. A briefing is arranged with those postgraduates who express a desire to work in the centre to discuss what the work involves, common issues and challenges and strategies for providing support. This meeting includes representation from tutors with significant experience so that this can be shared and questions answered. Following this meeting, new tutors are scheduled trial (but still paid) sessions alongside a more experienced tutor. After this, feedback is sought from both tutors, and as appropriate, an informal debrief held. If the sessions have progressed well, and all parties are happy, the new tutor is added to the termly centre rota.

When the centre described here opened in 2012, it did so with the aim of providing students with an additional source of support to aid their learning of the mathematical components of their programmes of study. Whilst accessible to all learners within the University, it was particularly targeted at foundation and first-year undergraduates and at students from other year groups identified as having particular difficulties with introductory mathematical and statistical techniques. In its first year of operation, it received a total of 482 visits, of which 85% were from students on programmes that would be classified as science, technology, engineering and mathematics, and the remainder by students studying other programmes such as economics, business, geography and sports science. By 2015/16 the total number of visits increased to 793. For the start of the 2016/17 academic year, the centre moved to a purpose-built location within the new main University Library which was in a much more prominent location. As a result, in 2016/17, total visits increased to 980.

A particular characteristic of this centre, and one which is highly relevant to the work herein, is the students who make use of it. Beneath these headline figures it is interesting to note that as a percentage of overall visits, the number made by students from the School of Mathematics increased from 34% (163 visits) in 2012/13 to 80% (786 visits) in 2016/17. It is very much the case now that the majority of users of the centre are specialist, that is single or joint honours, mathematics students. Further, and unlike many other centres, the majority of student users are in fact second and third year mathematicians: considering 2016/17 alone of the 786 visits made to the centre by mathematics students, 39% were in the second year of their studies, and 41% were in their third year. As such the centre described here is, importantly, not one which works primarily with non-specialist students at the transition into university which is the case often reported. While we do not discuss here the impact of the centre upon the students who choose to make use of it, its impact upon specialist mathematics students has recently been explored elsewhere (Grove et al. 2019b). The findings from this work show that students value the centre because of the convenient availability of support, its personalised nature with friendly tutors of a similar-age and subject profile, and the opportunity to use the centre as a group study space to work with friends.

## Theoretical Foundation and Research Questions

For the analysis of how the postgraduates learn and develop, their participation as mathematics support centre tutors and their personal trajectories through this role we draw upon the theoretical perspective of *communities of practice***.** This term was first used by Lave and Wenger (1991) to describe learning through practice and participation, emphasising the importance they attached to learning in a social setting (situated learning) in contrast to that of traditional learning theories. They go on to define a community of practice as a group of individuals who come together to share common interests and goals, with the aim of sharing information, developing knowledge and developing themselves both personally and professionally. Lave and Wenger (1991) also introduce the concept of *legitimate peripheral participation* to describe the way 'newcomers' to a community become drawn into a practice, develop and eventually (some) become 'old-timers'. Wenger, McDermott and Snyder (2002, p4) later defined a community of practice to be "groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis". In their paper expressly studying specific practices within a university, and especially those that concern the teaching and learning of mathematics, Biza, Jaworski and Hemmi (2014, p162) define a community to be "a group of individuals identifiable by who they are in terms of how they relate to each other, their common activities and ways of thinking, and their beliefs and values". Lave and Wenger (1991) suggest that the process of learning should offer individual learners opportunities to participate in the practices of a community whereby individual identity is engendered through a sense of belonging and commitment to the community. We shall see that using the framework offered by this theory enables us to examine systematically the community we are researching.

We now briefly describe relevant aspects of the elements of the theory. In Wenger's social theory of learning (Wenger 1998, p5) four components are identified: *meaning*, *practice*, *community* and *identity. Meaning,* or *learning as experience,* refers to the ways in which members of a community understand and talk about the environment in which they work, the activities in which they participate and their abilities to undertake the tasks necessary. As Wenger (1998, p53) notes, the making of meaning requires negotiation – "continuous interaction, gradual achievement, give-and take". Thus meaning can be changed through experience and negotiation. *Practice,* or *learning as doing,* refers to the perspectives members of the community adopt and resources they draw upon in their practice, on a day-to-day basis, which help to maintain their engagement in pursuit of the enterprise they are undertaking. The component *community*, or *learning as belonging,* represents the ways in which members talk about and draw upon the community, its structure and the way it functions. *Identity,* or *learning as becoming,* is concerned with the ways in which the learning that takes place impacts on and can change the members themselves.

Wenger (1998, p73) defines practice through three dimensions of: *mutual engagement* – ways of working, how this work can be done differently or better through observing and interacting with others, social relationships; *joint enterprise* – the negotiation that takes place to develop common understandings of what the enterprise is about, discussions of accountability, responses to local contingencies; and *shared repertoire* - resources through which meaning is negotiated, routines, words, discourses, tools, actions and "concepts which the community has produced or adopted in the course of its existence". Wenger (1998, p55) refers to two further concepts of relevance here: *participation* and *reification*. Participation refers to living or being within the community and taking part in its activities, interacting and negotiating and more. But it goes beyond simple engagement: as Wenger notes, participation is not something that is turned off once the specific context of engagement ends. Its effects will permeate other areas of the members' lives and as such is a constituent of their identity and will help shape it. Reification refers to the representation of some abstract concept by something more material and concrete and plays an important role in the negotiation of meaning. Wenger (1998, p. 58) states, "We project our meanings onto the world and then we perceive them as existing in the world, as having a reality of their own". So, for example, being an 'effective' community member is a rather abstract notion that might be reified by projecting the meaning of 'effective' onto more tangible attributes such as the skills a member has and the uses to which they are put. Given time and usage such a reification can start to take on a life of its own and contribute to the shared repertoire. Participation and reification are viewed by Wenger as being intimately connected because reification is crucial to the negotiation that is necessary for participation.

Communities of Practice theory has previously been used to explore learning in both formal settings such as schools and informal settings such as apprenticeships and playgrounds. Biza, Jaworski and Hemmi (2014, p161) have discussed extensively the theoretical foundations of communities of practice in university mathematics and describe learning as "a process of participation and reification in a community in which individuals belong and form their identity through engagement, imagination and alignment". Again in the university mathematics context, and specifically in respect of students working as partners in the teaching and learning process, Duah (2017) has used the theory to analyse both academic internships and peer-assisted learning highlighting the contribution that students themselves can make in improving the experience of mathematics undergraduates.

We now turn to the research which is the focus of this paper. The postgraduates who work in the centre are engaged in activities which go beyond that found in their usual university practice. Traditionally, in addition to their day-to-day research work, mathematics postgraduates undertake problem classes for specific taught undergraduate modules, where the course leader, a university lecturer or professor, will provide problem sheets for the undergraduates to work through, together with solutions for the use of the postgraduates. They may also undertake marking of assessed coursework and computer laboratory supervision. On the other hand, and crucially, when these postgraduates work in the support centre, the nature of the work is quite different in several important ways. Firstly, they have no prior knowledge of a student who walks into the centre seeking help. The student could be studying in almost any discipline (for example bioscience, economics, engineering, in which case such a student may not have studied mathematics beyond GCSE, i.e. beyond the age of 16) including mathematics. They could be from a foundation year, with or without an A-level in mathematics, a final year project student or a postgraduate masters or research student, and anything in between. This makes finding the appropriate level to pitch a response particularly challenging for the tutor. Secondly, they have no prior knowledge of the question they are likely to be asked. They must quickly learn to think on their feet and be willing to explore and research possible solutions in partnership with the student. For these reasons it is difficult to prepare for sessions - a marked distinction from the module problems class which is highly focussed and for which lecturers' resources are available in advance. On the other hand, to counter these two differences, the flexibility of drop-in centre work can often permit a tutor to spend longer time with a student on a one-to-one basis, to work together on a particular problem and to come jointly to a solution. Moreover, there is also the possibility of either referring to or working with the partner tutor on duty in the centre at the same time, or the wider mathematics postgraduate community as we shall see.

Thus postgraduates must *learn* to become mathematics support tutors. They do not do this in isolation. With just one day of formal training, their substantive learning is truly *situated* and takes place in the context of their participation in the life of the support centre. As the data will show, there is a strong network of other tutors upon which they draw and to which they contribute. We see this learning as taking place in the social context of their interactions with students, their postgraduate partner tutor in the centre, the wider group of postgraduate tutors and the academic lead in the School. We are interested in how the tutors make meaning of their role and in the negotiation required – for example, interactions, discussions, tensions, disagreements - to achieve this. We are interested to learn about the extent of collaboration between tutors – for example, the advice and support they offer each other - and between tutors and students who use the centre. To accomplish our overarching goal of understanding the role played by the tutors who work in the mathematics support centre and how they learn and develop through this experience we asked two research questions:

a) What is the role and extent of negotiation and collaboration in postgraduates *learning* to become mathematics support centre tutors?
b) What is the nature of this negotiation and collaboration and what is its impact on individuals and on their self-reported practice?

In this paper, we aim to respond to these through an analysis that draws upon the theoretical perspectives of communities of practice outlined above. Whilst the research questions arise pragmatically from a need to better understand the ways in which tutors work, the chosen theoretical perspective influences the data collected, how it is collected and how it is analyzed. There is a reflexive process between the research questions and the theoretical perspective which influences how we address the interview questions and how we interact with the participants. It follows that semi-structured interviews were an appropriate means of data collection. Further details are given in the following section.

## Methodology

For the semi-structured interviews, pre-prepared questions, which had been provided to the participants in advance of the interviews, covered five key themes: the mathematical background of the tutor, their ambitions and motivation for working in the centre; what the tutors know and think about mathematics support; the practices tutors adopt whilst working in the centre, the ethos of that work; tutors' views concerning postgraduates working in the centre; and, the skills and qualities tutors think they have been able, or hope, to develop through this work. Illustrative interview questions are provided in Appendix 1.

Whilst these questions gave focus to the interviews, the interviewer worked with prompts and sub-questions to follow up participant's responses. They were encouraged to speak freely about any aspect of this work they thought pertinent. In the spring of 2018, of the postgraduate population eligible to undertake teaching duties within the School, 21 were working, or had worked previously, in the mathematics support centre. All 21 were invited by email to participate in this research via interview; nine responded with a willingness to do so. Whilst we acknowledge that this is a self-selecting sample they are nevertheless representative of the tutor population as a whole. Table 1 provides biographical information on the nine participants, outlines the splits between pure and applied mathematicians and genders, and the lengths of their experiences as tutors in the centre. We interviewed the nine postgraduates over two days towards the end of the academic year in July 2018. The individual interviews were conducted by one of the authors who had no involvement with the postgraduates either in their work in the support centre or more generally in the School; nevertheless he had extensive experience of working in a support centre and therefore was aware of the issues that can confront a tutor. Each interview lasted approximately 45 min. The interviews were audio recorded and then transcribed.

Ethical approval was granted by the University. Appropriate ethical guidelines (BERA 2011) were followed. A description of the research was made available in advance, and at interview, all participants signed informed consent forms detailing how the collected data would be used.

The data thus gathered provided rich and complex narratives for each of the nine postgraduates. We chose to proceed thematically (Braun and Clarke 2006) and by following the coding process described by Creswell (2008). Thus, the analysis began with reading and re-reading the transcripts, and listening to the audio recordings to allow us to become familiar with the depth and breadth of the content and begin organizing the data. As noted above the interviews were conducted by one of the authors who also produced the transcripts, a key factor

**Table 1** Data on the nine postgraduate tutors who were interviewed

| Tutor | Gender (M/F) | Pure/Applied | Academic years completed by Summer 2018 | Number of years tutoring in the centre |
|---|---|---|---|---|
| A | M | Pure | 1 | 0.5 (one semester) |
| B | M | Pure | 2 | 2 |
| C | F | Applied | 2 | 1 |
| D | M | Pure | 3 | 2 |
| E | M | Pure | 2 | 1.5 |
| F | M | Applied | 1 | 1 |
| G | M | Pure | 4 | 3.5 |
| H | M | Pure | 2 | 2 |
| I | M | Pure | 2 | 2 |

which helped in this familiarisation and data immersion process and enabled insights to emerge. In-depth discussions of the data and its classification were undertaken throughout the analysis with the second author which formed an important check of validity (Creswell and Miller 2000). The following broad categories for data classification had been predetermined having been generated from Wenger's components and dimensions of communities of practice and the concepts of participation and reification:

- Components of learning: meaning, practice, community, identity;
- Dimensions: mutual engagement, joint enterprise, shared repertoire;
- Participation;
- Reification.

Then, working systematically, each transcript was read again, this time assigning the above categories to segments of text. Due to the small size of the data set, this process was performed without the use of software. So, for example, when Tutor H, describing the difference between tutoring in a module problem class and in the support centre stated "*In the support centre you can get asked about absolutely anything. So you don't have preparation - you have to improvise as you go along*" this was categorised under 'practice - learning as doing'. When asked how they might help a student when they did not have the required knowledge they stated "*what I usually do is direct them to some other postgraduate in the support centre*" and this segment was assigned 'joint enterprise'. As relevant text segments were being categorised descriptive codes were generated "in vivo" (King 2008). For example, when Tutor A stated "*I would basically guide them in this process of let's do things bit by bit.*" this was assigned the code 'scaffolding'.

Repeated consideration of these categories and codes enabled us to draw together interesting commonalities and differences amongst the participants, particularly in respect of how they were learning and developing in their role and the importance of interactions. We choose, following Wenger (1998), to report our findings using the four components, learning as: experience, practice, belonging and becoming, presented from the perspectives of, and through the voices of, the tutors.

## Analysis

### Learning as Experience

To establish a background to their role, postgraduate tutors were asked about their knowledge of the purpose of a mathematics support centre and what they understood to be their role within it. They demonstrated considerable empathy and an understanding of the many reasons why students might access mathematics support and in particular that it may be more accessible to students than other forms of assistance. Some tutors reflected on their own experiences as undergraduates and recalled the difficulties they faced. They are aware that students can find both mathematics and mathematics academics intimidating and that they, as postgraduates might be less-so. Their views reinforce the findings of Solomon et al. (2010) who describe support centres as 'physical safe spaces'. Convenience and informality of the learning environment also come to the fore, as noted by Lawson et al. (2001).

> **Tutor B**: *…you have...people for a whole range of reasons. People don't like knocking on professors' doors, it's much more approachable to go to young people your own age and get help; relaxed, readily available - the way it's there all day, if you're struggling it's something you can go in anytime.*
> **Tutor G**: *Well one of the big issues with maths is that…it's a scary world, a lot of people very often in the university will struggle because of curriculum issues, from being from another country, or not having done modules, or just because they find it hard…like when I was an undergraduate it was always very, a bit harder to go and talk to a lecturer about problems whereas postgraduates are more approachable in that sense.*

Tutors were asked about their motivation for becoming involved in the work of the centre. Several, expectedly, referred to the remuneration which was clearly welcome. However, many went on to describe the intellectual challenges both mathematically and pedagogically that they expected to face, how they liked teaching, and the skills that they intended to develop. They recognised in this work the opportunity not only to acquire and advance their pedagogical expertise, but also to hone and expand their own mathematical skills:

> **Tutor I**: *I quite like trying to teach things, at least at an undergraduate level because the problems aren't trivial normally...you have to have a think about them. So to come up with a way of doing it yourself is great and also trying to work with the students and make them understand what is going on.*

In terms of Wenger's component of *identity* and *learning as becoming*, (see later section 5.4) they saw this work as providing an opportunity for them to broaden what they do professionally, and to learn how to adapt their teaching styles to accommodate a broad range of learners:

> **Tutor D**: *...a skill that I always wanted to get better at is, it's not quite public speaking, but more to deal with people in a professional environment, to be able to adapt my teaching style to different people who might learn in different ways.*

They also referred specifically to the skills that they hoped to be able to develop through working in the centre. These included being able to respond to unforeseen and unfamiliar problems, and to devise alternative methods of solution or explanations tailored to individual's needs:

> **Tutor D**: *It's quite a good challenge because anyone can walk through those doors; you can't prepare for everything obviously, but you have to be prepared to try and tackle anything and that's a good skill to have. Something that I found really useful is when you try and help someone and they say `I don't understand your explanation' and you have to go right back to the drawing board. You've got to think of another way of getting to the same answer.*

Tutors were well aware that they would need to work with students from a variety of discipline areas. In fact, the opportunity to work with students from disciplines other than mathematics was a draw for some of the tutors, particularly in how they would learn to transfer their mathematical knowledge into new and unfamiliar domains:

> **Tutor F**: *...it's a different kind of experience that you get from doing normal teaching because that's just mathematicians; so I'll have people from, you know, from chemistry, geography, physics from different backgrounds asking for different maths help and you have to translate how you interpret maths to someone with a different background. It helps maybe train me in a way that just doing normal teaching…wouldn't allow.*

## Learning as Doing (Practice)

In this section we consider the descriptions the tutors provide of their practices whilst working with students, the resources upon which they draw to support this practice, and how, through experience gained, they learn to evolve their practice.

### Working with Students

To learn to work in the support centre tutors must be able and willing to think on their feet. There are important differences in approach depending upon whether the tutor is familiar or unfamiliar with the mathematics with which they are presented, and as a consequence, the extent to which they seek help from or offer help to other members of their community.

When the topic is familiar the tutors are able to offer scaffolding (a range of teaching techniques and explanations used progressively to move students toward greater understanding) and make up their own examples as they are working with the student. The following illustrative quotes demonstrate that some tutors possess good levels of pedagogical maturity: working to and fro with students to gauge their level of understanding and knowledge. They have the confidence to probe rather than 'tell'. They recognise the importance of drawing out solutions from the students themselves. They are willing to challenge. Consider, for example, Tutor B:

> **Tutor B**: *I will try and gauge where they're at. I ask them questions, you probe them a little. If it's part D you ask them how they did in Part C. You ask them...you never just show them the answer. You're constantly asking them questions and almost make them answer it themselves…I guess you learn through time that if you show someone the solution they don't understand it as well than if you make them come up with the solution themselves, and you can pick up on it - you can feel the penny drop...*

Tutor B, explicitly referring here to him learning through time the importance of engaging the students actively, reflects a deepening insight and the development of a 'teacher identity'. Likewise, Tutor H, insists that the student is an active learner:

> **Tutor H**: *So, I do remember, this past year there was a student who would come asking for help with the graph theory module and they were all problems that I could easily solve. What I would do is I would force her to do it. I would give them a pen for them to go to the white board and for them to write down everything that the statement says.*

Tutor H, went on to offer a strategy for problem solving but insisted that the student took ownership:

> **Tutor H**: *…because very often there is a lot of information in the statement and people become confused and do not know what to do with all of the information. What you need to do is write* [down] *the information and then try to combine the bits one by one to reach the conclusion that you want. So I make them go to the white board and write everything down. And you could do just small pieces and then just put them altogether to get the result. I would basically guide them in this process of let's do things bit by bit. Looking to this - just this - I know you can solve that - they solved it.*

The importance of probing in unearthing student's difficulties is evident in this quote from Tutor G:

> **Tutor G**: *Do you understand what the statement says? An issue with this approach is that often they will say yes, and then when you ask them what does that word mean, they say no...And something I have found out is that very often just by clarifying this word, at some point the student will say, oh can we try something like this. They may be right or not, but very often just at least that discussion is already a help.*

Sometimes however, this familiarity with the mathematical topic can lead to ways of working which are short-lived and need to be modified. This tutor described how, by drawing upon his own knowledge, understanding and approach to tackling a particular problem, which differed from that taught to the student, he caused more confusion. In recognising this he learned to adapt his teaching accordingly:

> **Tutor G**: *And if I know about the topic - I may know about the topic but from a different angle, or I may have learned it differently, so very often I always try to follow their lecture notes because at first I tried to do it the other way and sometimes I confused people*...[we needed to use] *some fairly advanced results that I find almost trivial, or I am so used to them that I use them without thinking and I could be using something from later in the course to…presume something...*

Adaption to individual students' needs was evident. The following excerpt describes how Tutor D became aware that the abstract nature of a particular topic in linear algebra was causing difficulties for a student who he thought might benefit from a more concrete approach, and how he modified his own approach accordingly. He was able to reify abstract notions as they had been taught by the lecturer, referring to the more familiar and concrete cases of two and three dimensions, and through analogy believed that this provided the insight required to help the student:

> **Tutor D**: *...there was one student* [struggling with] *these notions of dimension, basis; so one way of doing that is to go very abstract, to go from the definitions, and after this explanation it was quite clear that the student was not getting this so I went back to the basics, back to the example of Euclidean space, you have these standard basis vectors, so in two dimensions you get the square and in three dimensions you get the cube etc...and explaining everything through analogy with that.*

Tutor D went on to explain his strategy of explaining an abstract concept to this student not through a definition, which is the usual approach adopted in advanced pure mathematics courses, but by starting from an example and using that as a way into understanding the formal definition. As he said: "*and supplementing with the definitions rather than going straight from the definitions, helped that student.*"

The foregoing excerpts are typical of the approach adopted when the tutor was familiar with the mathematics. However, on many occasions students, particularly from disciplines other than mathematics, or those studying advanced mathematics degree modules, ask for help with material which is completely beyond the experience and expertise of the tutor. The interviewees were asked about their strategies for dealing with such situations. The response depended upon whether a second tutor with the requisite knowledge was available at the time or not. The following demonstrate the extent to which the tutors value and draw upon the support of their peers in the community:

> **Tutor A**: *…the ideal situation is because you are working in the support centre with two people, I have been fortunate enough to have - most of the time - the other person with me is someone who either was at [this University] before and took the course or someone who is working in that field of research.*
> **Tutor C**: *...my pure maths is fairly poor. Just because I did an applied masters. So basically I could do second year fairly comfortably but if a third year came in, rather than me spend hours trying to read around it, you know I'd be better off sending them to another postgraduate.*

But what happens when neither of the available tutors is a specialist? Neither knows how to solve the problem. It is evident that at this stage some tutors see the task as a joint enterprise and work together to try to come to a solution which will assist the student:

> **Tutor B**: *But it's when someone comes in with something that neither tutor is a specialist in - someone comes in with a partial differential equation or something, and it's me and a statistician or something - then we'll kind of bandy our strengths together and see what we...not always, but it does happen sometimes and I think that's a good thing too. Strength in numbers, and support each other as well...*

Tutor H offers an interesting problem-solving perspective in what follows, demonstrating the value of two tutors approaching a problem in different ways, one the 'brute-force' approach and the other bringing insight and elegance to the process:

> **Tutor H**: …*if it's something that neither of us have expertise on we usually try and work together. I can think of some instances with - I think second year analysis - when you have to consider integrals in higher dimension which again is something I haven't looked at in many years. Very often there are some symmetries in these problems so while one person focuses on what the theoretical brute force solution would be, the other person can think about how we can simplify the problem by getting rid of this half and just multiplying by two, and things like that.*

But what happens when the second tutor is already occupied helping someone else? When asked about how they deal with advanced, unfamiliar material, and when they have no immediate postgraduate peer help to call upon, they demonstrate a keen willingness to work *with* the student *to learn together*. They were also well aware of how their 'ignorance' can be turned into learning opportunities for the student often resulting in the student solving the problem for themselves and coming to a greater understanding (for both parties) through the negotiation that was taking place:

> **Tutor A**: …*they'll have to explain the problem to me…either I will understand it and be able to assist them, or the process of them speaking it out loud to me is sometimes enough to motivate them to have the thought that solves the problem.*

Thus dialogue and negotiation of meaning are crucial elements through which both tutors and students are learning in the support centre. In the following excerpt Tutor A asked the student to illustrate a problem using a diagram and this was sufficient for the student to come to a solution themselves:

> **Tutor A**: *I think the thing I can remember is random walks in combinatorics…they couldn't understand this and I was like - well explain it to me - and they were trying to use words and I was like why don't you draw me a picture of what this random walk could look like; and they drew the picture, and they went...that this could happen, and then as they were drawing the picture they were like well that can't happen, and you ask a simple question, why can't that happen and they say it can't happen because we have this property and you say well turn it into a solution...*

Enabling students to see that the tutors do not know all the answers but even then that they can demonstrate problem solving strategies is evidently one of the benefits of learning in a support centre environment - and one which is not normally apparent in a lecture or problem class.

> **Tutor B**: *People have come in with their undergraduate thesis and all kinds of stuff where they have papers, maybe something I am not familiar with…we just kind of sit down together, read through it. I do the best I can.*
> **Interviewer**: *Is it a process of trying to feel your way through it together?*

> **Tutor B**: *I think that helps them a lot as well. I think when they see the process of the instructor figuring it out, walking them through it, I mean it's not staged or anything, it's the genuine thing of this person beside them trying to figure it out just the way they've been trying to figure it out.*

The idea that the tutor too struggles and that it is important for students to see this was evident in several interviews as Tutor H's quote illustrates:

> **Tutor H**: *I do remember a problem about optimisation which also required tools from linear algebra…I think the module was a third year module, but the linear algebra tools were first year tools. I did spend about 20 minutes only to understand the notation and the problem. Once I understood everything I just realised, ok this is first year linear algebra, I can solve this. They were sitting with me and they saw that I was struggling and they were trying to explain to me the notation too, which is good.*

Tutors were able to be quite specific about mathematical areas where learning collaboratively was crucial for progress. Here, Tutor F refers to reading lecture notes together, highlighting important parts and making suggestions which lead to success:

> **Tutor F**: *So this module called continuum mechanics that the third years do in the first term. That's quite abstract stuff so you need to know the lecture notes - it's different from a lot of other courses - I didn't have any experience with…I didn't know the material. So there was one question where you were trying to convert one form of a partial differential equation into another using manipulations you learn in class. So we just kept on looking at this example and I said, oh they've done that in this example, have you done this, and this time it was no, so I said try that - I just sat by him while he was working it through it...that worked.*

Even when the solution of a problem defeats both the tutor and the student some tutors believe that there are learning opportunities for both parties. In what follows Tutor D, even though he could not solve the problem in-hand, talked through his strategies, explaining his thought processes, and importantly, what he was doing and why. This dialogue is invaluable for the student and is an excellent demonstration of the perseverance that undergraduate mathematicians need to develop:

> **Tutor D**: *Yes - we were doing all these crazy things...in terms of results it was a wasted half hour because they didn't get the answer but I hope it was useful trying to...so everything I was mentioning I was talking through why I was thinking this might...In those situations the strategy is quite important to get across. Right, I am going to try this - this is why I am going to try this - this is what I am hoping will happen when I try this. When that didn't work I go back to the drawing board. What can we try next?*

This was not the end of the matter. Here we see an excellent example of how Tutor D did not simply 'turn off' his engagement at the end of the session, but the problem stuck with him and bothered him for quite some time:

> **Tutor D**: *This problem stuck with me - because I'd spent half an hour on it, I couldn't do it. Eventually I had to say - look, I'm really sorry but I can't. I asked the other postgraduate - they couldn't do it either. It was really spinning in my head for a couple of weeks. Then, a couple of weeks later a different student came in with the exact same question and because I had been stewing it over a couple of days before, I had actually come up with the answer. So I was able to say, this is what we are using in this question.*

This permeation into areas of the tutor's life beyond the support centre is a fine illustration of *participation* as understood by Wenger (1998). Moreover, by being able to draw upon what the tutor has learned outside the centre, he was able to help a subsequent student. This immersion by the tutor in the life and well-being of the centre helps to ensure that it functions effectively and, in the tutor's view, benefits students.

When the solution of the problem in-hand remains intractable - notwithstanding the work done with the student and with the second postgraduate - tutors referred to how they would frequently take the problem, at the end of the session, back to their peers. We evidence this in the section below on *learning as belonging*.

Some tutors highlighted differences in practice when working with students from other disciplines and how they would tailor their work to the discipline and background of the student. The following excerpt demonstrates a sensitivity to the needs of the student and a recognition that not all require the same level of rigour as a student studying mathematics:

> **Tutor I**: *Sometimes you want to tailor your responses slightly...just because the ways things are done in the maths department is always very rigorous and formal and sometimes, say engineers just get completely confused by that. Sometimes you might want to go through a full derivation and show them where it all comes from but they* [engineers] *just get lost half way through so you skip the middle bit and say this is essentially this, and look at it a bit, and it looks about right and they are happy with that.*

Tutor I continued by explaining that, as a mathematician, he sometimes found this approach uncomfortable, but recognised this pragmatic approach was sometimes appropriate:

> **Tutor I**: *I don't like to because it's always good to have a formal approach anyway. When they can't understand the full generality you can just skip the details.*

However, this was not always the case, and some tutors referred explicitly to their primary focus being the 'question' or the 'mathematics' and not the student. Tutor D was probed about whether it was important to know at the beginning which department students had come from:

**Tutor D**: *It probably is but I try and really focus on the question itself. It is sometimes fairly obvious. Certainly with maths* [students] *I am fairly familiar with which modules happen when and so this question is probably in this module this year. If they are sort of asking something outside that, that's a good indicator they are not a maths student and I maybe adjust my style accordingly. But I do try and focus on "ok this student has this problem, here is how I would normally tackle it*".

Notwithstanding their earlier comments about tailoring their responses, Tutor I, when asked if they treated biology and economics students turning up at the centre any differently (from mathematics undergraduates), stated:

**Tutor I**: *No. I occasionally have to ask what they know so that I can actually avoid just confusing them. Not really. It's about the same...Normally they just come with a question and I just start dealing with that.*

We shall return to this critical issue of primary focus - the student or the mathematics - later.

### Drawing upon Resources

The predominant resources referred to by the tutors are the lecture notes of the student, or the lecturer's notes available on the virtual learning environment (VLE). One tutor referred to lecture notes from modules previously studied by the student that would sometimes be referred back to:

**Tutor E**: *I ask them, do they have their notes. I read their notes - see what they have written.*
**Interviewer**: *And when they don't have notes?*
**Tutor E**: *A lot of them do bring smart devices - laptops, tablets and stuff and I'll bring it up on there.*
**Tutor H**: *I think I have referred students to their own lecture notes both from the same module and from other modules. So if someone is asking me about a problem that I know they have solved in the previous year or I know appears in a very similar way in the notes, I just tell them look at these - it's very similar.*

These quotes serve to illustrate the importance of students arriving for support at the centre with a good set of lecture notes if they are to maximise their opportunity to learn from the tutor. The provision by the lecturer of high quality notes on the VLE serves as a fall back when, for whatever reason, the student's own notes are not available.

There is some evidence that the tutors draw in an impromptu fashion upon artefacts that are available to help illustrate the teaching points they are trying to make. Here Tutor D reports how he was able to illustrate key aspects of spherical trigonometry using the hemispherical top of a water bottle:

**Tutor D**: *The student had a very large water bottle. Let's have a look at this water bottle. The top was a hemisphere. I want to describe some point on here. So what are the two...you can describe this in two parameters. How can I describe this* *point precisely? We need to pick the latitude. Ok, how can we describe that? We've got this point, it's on this latitude; for every point on this latitude, we can describe that by this angle here. Similarly, we have this cross-section that we are on. How can we describe which point on the cross-section we are on? Well we can move around on this, so this gives us the other angle. So once they were able to say "I know what these angles mean", we were able to go back to the algebra and say that's why this expression has these two important angles and that's all we are doing.*

Drawing a relevant diagram or picture was frequently referred to as a means of producing a useful learning tool, in this case a tree diagram to illustrate probabilities:

**Tutor D**: *Let's go into the algebra - the algebra wasn't helping them. So right, let's look at this probability. Let's draw it all out as a tree diagram; so a terrorist enters zone 1. Do we detect them, do we not? If we do detect them, do we catch them or do we not catch them? So, using this we were able to isolate each part of the formula that corresponds to each of these events.*

Other tutors referred to video resources available online to which they had directed students:

**Tutor F**: *In fluid mechanics there was an enthusiastic student so we got talking more about the actual area and there's this YouTube video on laminar flows. It's quite a good YouTube video displaying this thing they see in equations, so I said this is it in real life, you know.*
**Interviewer**: *Did you show them it?*
**Tutor F**: *Yes. They seemed to find that interesting.*

Practice in the centre provides opportunities for postgraduates, on occasions, to share their more general experience with the students and to explain aspects of their own research:

**Tutor G:** *I talk to them and even sometimes some people have asked what I have been doing as part of my research...there are some second or third year keener students asking about that because sometimes they will have a module that only a few of the postgraduates will know about and they finally find someone who can help them. And then they are probably happy about that.*

Finally, mathematics support clearly provides an environment in which interpersonal skills such as empathy and sensitivity can develop. These aspects are discussed further in Section *Learning as becoming*.

## Learning as Belonging

In this section we consider the descriptions the tutors provide of how they learn through the support of the community of postgraduate tutors. They discuss the composition of that community - how it is comprised of tutors with different academic interests and areas of expertise (e.g. pure mathematics, applied mathematics, statistics), and how they know about these things and importantly, how they exploit these differences in support of their own learning and that of the students visiting the centre. They refer to tutors being at different stages of their academic careers, and how those with more experience ('old timers') support the newer members and assist in the maintenance of the community. They describe their understanding of what it means to be a 'good tutor' within the support centre environment, describing attributes that they have witnessed and often emulated.

There is substantial evidence that the community supports learning – but not just within the bounds of the centre a fact which further illustrates the truly participative nature of this community. Outside there are regular discussions about mathematical problems arising which tutors have been unable to resolve, pedagogical issues, and tensions and contingencies that have arisen (e.g. dealing with difficult students or peaks in demand). Collectively these characteristics help the community, and as a consequence the centre, thrive, and provide an engaging and rewarding working environment which provides an additional and welcome dimension to the academic lives of the postgraduate tutors.

### Drawing upon each Other

The tutors are part of a strongly networked postgraduate community within the School of Mathematics. Not only are they all based within the same academic department, they interact professionally and socially. Many share a large open-plan office space, they attend seminars and short-courses together, and they provide collective teaching support to large undergraduate modules. There is also an active postgraduate society that organises both academic events, for example research conferences and poster presentations, along with weekly social activities. The pre-existence of this network helped enable the community of tutors to thrive, to readily call upon, learn from each other's practice and help each other. They were able to articulate how they drew upon each other:

> **Tutor H**: *We pretty much have a good networking here so we know all the postgraduates in the School and you know what area of expertise they have. You know what they are working on for their PhD's. So I just try to look up the names of my colleagues and...if the student is asking me about dynamical systems I will go to someone who does analysis or applied maths who will hopefully be able to help.*

> **Tutor B**: *There is two of us scheduled at any time so if the other guy or girl is specialist in this then I would bat the ball to them; if I really feel it's something out of my comfort zone I can get the timetable up. I can refer them to a slot when someone who is a specialist can...*

Tutors were asked how they knew about the skills of the other tutors, and how they were able to access these. They referred to tools that assisted in this endeavour and specifically a list of tutors' skills that had been prepared:

> **Tutor A**: *Everyone's quite aware of the areas that the other people work in at that level…we have a sheet that was sent round amongst all the tutors to say this is what we can specialise in...*

They themselves had instigated technology that would enable real-time communication between a tutor in the centre and other tutors outside, referring to the 'group chat' phone apps to which they have access. Clearly, even tutors who were not directly engaged in the centre at a particular instance were participating by being able and willing to offer advice from a distance:

> **Tutor C**: *...so I would just put a message on the group chat and say "hey can anyone do this thing? I'm struggling" and then if that person didn't reply and say "yes I could", someone else would probably reply and say "oh,* [X] *could probably do that".*

Evidence that postgraduate tutors work together in the solution of a student's problem has been described in Section *Learning as doing*. The extent to which this can take place of course depends upon how busy the centre is and upon the skills each tutor has. Tutor B's comment below exhibits both an interest and a keenness to engage in the joint enterprise of helping students:

> **Tutor B**: *If it's quiet sometimes and someone comes in - some people - I would like to think I am one of them, there's definitely others - if a person comes in and they're talking to this tutor and the tutor is kind of working with them, the other person might come over as well and they'll both work together.*

### Old Timers Supporting Newcomers

There is substantial evidence that 'newcomers' to the practice are supported by the more experienced tutors. But the role of the old timers goes further than providing support. They provide models of mathematics tutoring. Through observation the newcomers internalize the notion of being a 'good teacher' and report how they emulate what they have seen:

> **Tutor H**: *There are quite a few older postgraduates…if I was struggling with some problem I would ask for help. There is also the process of observing how more experienced people do it and you can copy things you really like that they do, in particular this idea of forcing the student to solve the problem. I picked that up from another postgraduate who was working there.*

The mere presence of a more experienced tutor in the centre with a newcomer assists in alleviating any apprehension they may have as reported by Tutor A:

> **Tutor A**: *...in those first four weeks...I don't want to say* [I was] *nervous, but maybe a little less confident to just sit someone down and try to figure out a*

*problem in front of them, so then you have this...a fourth year comes along who as12 been doing this a long time and has probably come across that problem themselves - and even if they don't cover and start teaching it - it's all support…*

Outside the confines of the centre, discussions continue and 'old-timers' give advice on practices and ways of recognising and responding to affective issues that students may have. This included offering reassurances to students who were worried or anxious.

**Tutor F**: *I used to talk to a tutor called* [name] - *and he was really good at teaching people; he's left now, but that was outside the maths support centre he used to talk about things and say what he did and how he taught in the centre and...*
**Interviewer**: *Can you think of any specific things he advised you to do or not do?*
**Tutor F**: *…sometimes if you have students who are getting stressed and worked up about not getting something he said like keep on emphasising, so quite often they've already done a part, say you've done that bit, so you know that stuff, you know this stuff you just need to…get more practice, and say like* "*oh you've got some time, this is what revision is for, you know…to learn this stuff*".

Throughout the interviews the notion of being a 'good' support centre tutor was reified by the interviewees in several ways. So, Tutor H, above, has learned that involving the student actively in the problem solving process – 'forcing the student to solve the problem' - is effective and is a characteristic of a good teacher. Tutor F refers explicitly to a peer as being "really good at teaching people" and through probing is able to concretise this in terms of having a sympathetic attitude and offering constructive advice.

There is also evidence that more experienced colleagues, spotting that there were issues arising, would actually intervene during a session and that the new tutor valued this:

**Tutor F**: *We had this difficult student; sometimes, if he didn't get it…he'd become annoyed and it would kind of seem like he's annoyed with you. He could be quite difficult. There was also this tutor called* [name] *who was in the centre at the same time; she was looking over and occasionally put a word in to try to...help him…I was trying to explain things to him. She just managed to word it in a different way which actually seemed to help.*
**Interviewer**: *She wasn't intervening about his annoyance, she was intervening to try and help him with the maths*?
**Tutor F**: *Yes - to explain it in a different way...Obviously in my first year - I'd not had that much experience whatsoever. My first term, my first couple of weeks and she helped me out.*

The role of some of the 'old timers' went beyond supporting their less-experienced peers. They were found to be supporting the centre manager in recruitment of new tutors and thereby helping to maintain and grow the community. Here Tutor G goes so far as to recommend working in the centre:

**Tutor G**: *I think it's* [the centre] *a good idea and I would encourage all the first year postgraduates to try to do it...the new people when they come they have this* *introduction to teaching with* [name]. *The centre is advertised to them, and sometimes some of them are like "is it useful" or "is it not useful". And myself and lot of other tutors have tried to encourage them to help.*

Through the conversations in the office, postgraduates who are not tutors are often inspired to take on the role in the future:

**Tutor F**: *People talk about it and the other students, similar first year people this year, are tempted to do it next year, because of how I've talked about it...so from hearing what its actually like they've said ok yeah I can do that, you know.*

## Outside the Centre - and Still Learning

To follow up on the notion of community maintenance, the tutors were asked about the extent to which, *outside* of the support centre, they continued to support or be supported by other tutors. Tutor H, here, was receptive to a request for help from another:

**Tutor H**: *In particular there was one time when someone came to me and said "I was struggling with this problem in combinatorics that a student brought up and I couldn't solve it, how would you solve it?"*

and confirmed that he did indeed offer advice. Tutor A referred to how he was able to learn something about fluid mechanics from peers in his (pure mathematics) research group because they had previously studied that module whilst undergraduates at the same university. He was later able to put this learning into practice when tutoring in the centre:

**Tutor A**: *…a large number of the PhDs here did their undergrad at* [university] *so they have taken the course. So maybe I'll talk to someone who's also in the algebra group about a problem in fluid mechanics, just because they happened to take that as an undergrad and they'll be able to answer.*
**Interviewer**: *So have you been able to learn from this other postgraduate and then go back and advise a student differently?*
**Tutor A**: *Yes, absolutely.*

When discussing the nature of communication amongst the group of postgraduate tutors that went on outside the centre there were clear examples that this was taking place, in part, to forewarn colleagues about impending deadlines and likely topics that students would seek help with. Tutor E's comments are illustrative:

**Tutor E**: *We'll have a session, we'll come out and we'll talk about what questions we got asked and how the students were. Sometimes it's like a heads-up to say oh this week many students coming to ask questions on…we find out when the deadlines are because the students talk to us - this is this module, we have this*

> *exam(ple) sheet and it's in for this day, and so we relay this information to each other. We know when there's gonna be like a build- up of sheets...*

Tutor A went further and explained that he had advised tutor colleagues that a particular student would be asking for specific help and invited them to prepare a response prior to them attending the centre on the following day:

> **Tutor A**: *If there is a problem that I can't solve I maybe say come back tomorrow, then I go back to the building* [i.e. the postgraduate tutors' shared office] *and I say - I've said for someone to come in tomorrow - this is what the question is, maybe you can prepare an answer to give them. The office I work in has…20-30 students, so we have someone from every area of research so if I can't do something I will say…pre-emptively, someone is going to come in tomorrow and ask you this question…*

### Using the Community to Work Together to Resolve Tensions

When asked about tensions and disagreements arising between either tutors or tutors and students, there was little evidence that problems were arising. There was reference to one or two students who became such regular users that this became a nuisance and was unfair to others but the situation was resolved through the intervention of the centre manager:

> **Tutor G**: *There have been one or two students which pushed some of the tutors a bit in that they were in very often and asking the same thing to a lot of different tutors. It's not common...We've had discussions about whether the centre was used properly, whether some people were abusing...some of us from the centre would have talked about that and then one of the people would have gone and talked to [centre manager].*

The interviewees were well aware that should issues arise, there were mechanisms to raise them:

> **Tutor G**: *[Centre manager] has meetings every term with the people at the Library - like there is always an email and we try to think of things to mention.*

There was little evidence of disagreements between tutors but the following quote shows the spectrum of empathy and understanding, particularly in respect of students from different disciplines:

> **Tutor F**: *There has been disagreement with this one tutor about how he interprets students who need help. He can be a bit arrogant - having seen him teach in the centre he doesn't bring that into the centre, he's fine, but when he talks about it afterwards he was like saying this person was an absolute idiot - and I'd say no - they're just struggling a bit - people have different skill sets so maths is not their forte - but I've seeing nothing like that - he doesn't bring it to the centre.*

## Learning as Becoming

Working in the centre provides significant opportunity for personal development, mathematically, pedagogically and in terms of more general transferable skills. Tutors were asked about whether working in the centre provided a valuable additional dimension to their working lives. They went on to report how they perceived this work had enabled them to become not only better teachers but better at mathematics. Through the interviews they were able to reify these notions. Some reported becoming 'more professional' and described the professional pride that they took in learning how to solve problems in previously unfamiliar areas, how to better communicate with students and how their practices change in order to 'become better'. Some reported that their experience had impacted upon them sufficiently to consider modifying their career aspirations. Others reported a growing confidence sufficient to enable them to suggest changes to university teaching practices. These aspects will be explored in what follows.

### A Valuable Dimension

The students were asked if they enjoyed working in the centre. This work was an eye-opener for Tutor D who hadn't expected that he would like teaching:

> **Tutor D**: *I do. I would say now that I enjoy teaching. I don't think I realised that until I started working in the centre...And doing the support centre work is very one on one, or one on a small group. It has definitely opened my eyes to the fact that I actually do enjoy teaching…*

Tutors C and I valued the opportunity this work gave them to maintain interest in mathematical topics that would otherwise have been left behind:

> **Tutor C**: *I think that it keeps you a lot more linked with what you did in your undergraduate* [degree] *because you are constantly reviewing it - so because a PhD is so specialised it is so easy to forget and to get rusty.*
> **Tutor I**: *If nothing else it gives me more experience looking at the other areas of maths that maybe I haven't done them for a while, or I've forgotten details from them. They are not the ones I already teach here so it's nice to see that occasionally because I can remember how things work. They are unlikely to be useful to me again at some point but it's just nice to...*

The fact that Tutor I believes that exposure to other areas of mathematics through working in the support centre is "just nice" even when "they are unlikely to be useful to me" is an affirmation of a maturing identity as a mathematician and an important by-product of participation in the life of the centre.

### Becoming Better at Maths Teaching

There are numerous references in the interviews to "not being a very good tutor" or "not being as good as I would like to be". These notion are reified in the illustrative quotes:

> **Tutor E**: *I noticed when I first came in I was not very good at being a tutor. I wasn't very good at hiding the answer - stuff like that. I try and not solve the problem for them - that's something I definitely did when I was starting - I think I got excited and did it for them.*
> **Tutor F**: *I can think things in my head but I struggle to explain them to someone else. I think that's my main reason why I want to continue in the mathematics support centre to get more practice, because that it's never been one of my strong points.*

Tutor E went on to say that his practice had changed, now working on a whiteboard so that students could not simply take a paper solution away; "*they have to copy it down in their own words and … that hopefully helps their understanding*" We have already noted Tutor G (*Section Learning as doing - Working with students*) above who admitted that he had "confused people" by approaching an explanation from a different angle to that of the lecturer. Whilst this can often be a useful strategy (e.g. Tutor D in *Section Learning as doing - Working with students* who by concretising the lecturer's abstract notion of a vector space overcame a blockage in a student's understanding) this awareness led to Tutor G's change in practice. Tutors describe adaption through experience, becoming better, but recognise with some apprehension that they are on a journey and not necessarily there yet:

> **Tutor H**: *I would like to think that I can - I don't know what the word is - transmit maths better, in a way that's more understandable for undergrad students…But I can't really know. I think it also depends very strongly on each particular student. The same way of teaching will work for some and not for others. I try to adapt but I am not confident that I am able to do so - at least not just yet.*

Through working in the centre, the postgraduates learn about themselves and how they are evolving to become better teachers. Here they refer to developing the confidence to acknowledge their own shortcomings:

> **Tutor D**: *I always think it is important to show that just 'cause you are a postgraduate or lecturer you can still make these mistakes and there's nothing wrong with doing that…I am definitely more prepared to take on these questions that I may never have considered before; I feel like my explanation skills have got better; I am better at trying to understand how the student's going to learn this best, to try to tailor an explanation to that; where I can say I have got better is that I am better at detecting when I am hitting a dead end.*

Finally, practice in a support centre clearly provides an environment in which interpersonal skills such as empathy and sensitivity can develop:

> **Tutor B**: *I am sure I've learnt loads doing it. It's not just about helping them do the homework - you could have a robot do that. It's about showing them there's nothing to be scared of, keeping them calm, inspiring that little bit of confidence in them because that goes an awful long way...I think stuff like that, the human*

> *side of helping them has been something I've come on a lot...I think that's something I've picked up on a lot more in the last year or two. It's not about the maths as much as it's about this person.*

### Becoming Better at Mathematics

Specifically tutors described how they were also learning to be better at mathematics per se:

> **Tutor I**: *I can think of one* [problem I couldn't solve] *which was just a simple thing. It was an integral of some sort. It looked like it should have been very easy. I went back to the office and within five minutes I'd solved it...*

Tutor F went further. He reflected upon being unable to solve a problem in an unfamiliar field - continuum mechanics - that had been presented to him in the centre. Identifying as a mathematician, he believed he ought to know more about this field and endeavoured to address this.

> **Tutor F**: *Yes there was one in continuum mechanics - I've actually looked at the lecture notes and sighed and said you* [i.e. the tutor himself] *should learn about some of this stuff and some of my PhD friends were actually doing that module* [at this university, PhD students study some advanced undergraduate modules] - *so when I came back from the centre I said can you get your recent assignment up because I was stuck on that question...So then the solutions came out for that module, I looked at those solutions.*

Moreover, he acknowledged that working in the centre provided a good opportunity for widening his mathematical horizons:

> **Tutor F**: *I think the centre is great for that because it helps…you explore modules.*

Tutor D refers to changes in the way he himself thinks about mathematics, and thinks more broadly around the subject, through his encounters in the centre, again illustrating a strengthening of identity as a mathematician. When asked whether tutoring in the centre has helped his own understanding:

> **Tutor D**: *I think it has. I have always understood things in a very particular way, but having to think my way around these other viewpoints has certainly helped give me a broader perspective on the maths I know. I can't give a concrete example but a lot of things I think it's that because of the definition; its helped to see that's why that's the definition. That's certainly been useful. I don't think I have particularly used it in my own research but it's been useful for thinking around the subject.*

### Career Aspirations

Some of the tutors aspire to become university lecturers and they were asked about how their experiences in the centre might support their development. They referred to the nature of the work in the centre being complementary - “different sort of teaching” from tutorials and problem classes where they know what to expect and are provided with solutions - and how it would prepare them for dealing with unexpected contingencies:

> **Tutor G**: *Something I have never done for the department, is the tutorials...On the other hand, in the centre, it's a less formal setting but I have done that - so that's a different aspect of teaching that I have seen only through the centre...*[It's a] *slightly different sorts of teaching. It's not the same with a small group or a larger group, asking questions, answering questions when you know the topic and you have been preparing for the hour, as opposed to when the question comes as a surprise like there have been times when someone will ask and it's taken me 5 minutes just to remember what the words mean because asking them to clarify what their question is is not just for them - it's also to help me remember what they are working with.*

Tutor D enjoyed the work so much that he described modifying his career aspirations so that he might be able to focus more on a teaching-oriented position:

> **Tutor D**: *I would still like to carry on this sort of teaching responsibility. I don't know how or I might see a job that's more focussed towards that than the academic research and lecturing...If I had two similar academic job offers and one had more… that would be the one I would probably go for…*
> **Interviewer**: [the one with] *the teaching in? And this is something that's changed as a consequence of you working in the centre?*
> **Tutor D**: *I think so.*

### Skill Development

When asked about themselves and whether they have developed more skills, it was evident that working in the centre provides opportunity for tutors to do something different to what they would have done as an undergraduate or postgraduate. Several referred to having to develop their communication skills, an aspect which is often quoted as lacking in traditional undergraduate mathematics degrees (Inglis et al. 2012):

> **Tutor E**: *Probably. I'm probably more articulate about maths now. I know that I am sometimes not the best communicator - but it's going to improve - I'm aware. So it is helping me to improve on that which I am grateful for. It's good to learn - one of the best ways to talk about maths to people is to explain it.*
> **Tutor F**: *I think I've got better at explaining things, which has never been my forte.*

Tutor F went on to note how this was very different to a problems class where he could read a solution prepared by the lecturer and repeat the explanation to the student. In the centre he needed to formulate the explanation for himself and communicate that to the student.

### Growing Confidence to Influence Developments

The intelligence gained through working in the support centre enables tutors to have informed opinions about how mathematics teaching might develop in the university. Tutor I expressed the concern that when a mathematician teaches a mathematics course to students in another department, here economics, he or she may not be sufficiently well-informed about the backgrounds of the students:

> **Tutor I**: *A lot of universities will have taught courses where the mathematicians just teach a thing to economics students...and the mathematicians never see that course. I know a lot of the time they are actually missing on the assumed knowledge so they assume lots of things that people have no idea about.*

He went on to give a specific example concerning proof by induction – a technique that the lecturer had assumed, but which was apparently not known by the engineering students that he was helping:

> **Tutor I**: *I saw an example in engineering here where the course was taught by a mathematician and everything in it was incredibly basic but it had like a proof by induction in it and they, I think, at least as far as the student was concerned, they had never seen that before and it wasn't taught in this course anywhere, because it was an engineering course. They didn't know what that was.*

Tutor B referred specifically to the way that working in the centre might help to ground a prospective lecturer and enable them to acquire valuable experience that might not necessarily be available otherwise. He suggested that working in the centre might enable a lecturer to recall difficulties of their own, and thereby have some empathy for someone who was struggling, and then be in a better position to be able to help them:

> **Tutor B**: *The fear would be if you just go through your own career - undergraduate, masters, PhD, postdoc, you end up lecturing, you just keep going and a fair amount of time elapses; if you do that just by yourself you won't remember what it was like back then for yourself and that's really important to...you know…the concept of something back in primary school now - adding numbers or something - I can't imagine what that was like but it's important to remember what these things were like, the tricky bits of learning these things about a derivative, or about an integral or whatever, because when you know that you know exactly what someone is going through and you can help them.*

As a follow up question, tutors were asked whether working in a centre would be good professional development for all academic mathematicians. Tutor B believed this to be so because he himself was keen to understand the areas that his students were struggling with. However, he recognised in his response that perhaps not all professors might be able to come down to a level appropriate for some students:

**Tutor B**: *I think so, completely, yes. Like, some of the best professors I ever had, they just would not be able to explain a simple thing to some students. I don't know if it was just something they thought you need to go and figure out for yourself, maybe it's just a difference of philosophy or if it was just - I often feel in some sense - they just weren't getting why the student wasn't getting it and I wouldn't like to end up like that…I want to always be at the coalface where I can see where the problems are happening, what the tricky bits are and even if it's all easy for me I want to know why someone else would have trouble with it.*

Tutors were asked whether they had taken something they had learned from their experiences in the centre back to the department with a view to informing how things might be done differently in mainstream teaching. There was no evidence from the interviews of this taking place but Tutor A went on to describe communication as an area for potential improvement:

**Tutor A**: *No but I think it's something that's missing right now: I'm going to sound very general when I say this, but it's communication between the tutors and the lecturers on the courses, I think this is missing not just in the support centre but also within the examples classes...In my experience of teaching in either, I have never had to report back to anyone who runs a class.*

Tutor A referred to a specific issue in statistics teaching that he felt ought to be communicated to lecturers. He became concerned that the students he had seen in the centre appeared to know statistical definitions but their understanding went little beyond that. He felt that a lack of deep learning that he was witnessing in the centre might well not be apparent to lecturers who were marking assignments:

**Tutor A**: *Stuff like...first years in statistics, they have all these definitions, but for the most part it's not deep learning, there's no...for a lot of them there wasn't a sense of this is what you are describing. The lecturers just see, for the most part, the work handed in, which a lot of the time isn't very enlightening in determining whether a student actually understands something - it's generally just surface.*

This tutor emphasised the very distinct way in which working in a support centre can garner intelligence about student learning that is not available to a lecturer teaching a very large class of undergraduates:

**Tutor A**: *We have the one-on-one experience that the lecturers don't give them and that's when, in a class of however many first years in a class, very few people are going to speak out, whereas if you are one-on-one with someone in the Library, they kind of have to speak at that point.*

Asked whether, if they were in a position of power/responsibility, would they change things, Tutor D suggested that all mathematics undergraduates should have small group support sessions with a postgraduate:

**Tutor D**: *I would try and organise small support group sessions - four or five students to one postgraduate or one fourth year - maybe once a week particularly for first years...because again, these students that go through their entire degree without getting any of this benefit from one-to-one small group mentoring.*

Tutor F noted that if there were better feedback mechanisms from postgraduate tutors to module lecturers this would be helpful, particularly when lecture notes are not clear or are incorrect. He suggested that postgraduates might have more influence in this respect than undergraduates.

**Tutor F**: *Maybe they'll take it more seriously when a PhD students flags up a thing saying this is not good; maybe they'll take it more seriously than just coming from a* [undergraduate] *student…there was this person doing an environment course and they had some equations - the way they displayed the maths confused me. It was just completely terrible - they needed brackets - I had to presume brackets at certain places, and it was confusing and I had to say, admit to them, as a mathematician how they've written that is confusing - this is not your fault - however your lecturer has written that.*

## Discussion and Conclusion

To achieve our overarching goal of understanding the role played by the postgraduate tutors we asked two main research questions: a) What is the role and extent of negotiation and collaboration in postgraduates learning to become mathematics support centre tutors? b) What is the nature of this negotiation and collaboration and what is its impact on individuals and on their self-reported practice? To answer these questions our interview data from nine practising tutors was analysed through the lens of communities of practice. Specifically we used Wenger's components of social learning - *learning as experience, learning by doing, learning by belonging* and *learning as becoming*. Because the nature of tutoring in a support centre is quite different from other aspects of the postgraduates' work, they must *learn* to become tutors and then *learn* to become better tutors. By and large, this learning is situated 'on the job', drawing first of all upon their own experiences of how they have been taught and what works for them. However, they soon learn that this is insufficient.

We have seen [e.g. Tutor G - Section *Learning as doing - Working with students*] that when there are multiple ways of approaching a mathematical topic the method known by the tutor may not be the one that has been taught to the student, and to pursue the tutor's preferred approach can lead to confusion. It becomes necessary to learn to adapt and to modify practice. The tutors, who by definition are high-flying academic mathematicians, and particularly the pure mathematicians, think about mathematical concepts in a very abstract and theoretical way. Engineers and other non-mathematicians, (and even some mathematics undergraduates), [e.g. Tutor D - Section *Learning as doing - Working with students*] find that trying to learn through concrete examples and applications can lead to better understanding and progress. This necessitates a mathematical paradigm shift that some of the postgraduate tutors were able to take on board as they developed their teaching. To others this did not come naturally. The ability to improvise and think on one's feet becomes particularly important in the context of a university-wide support service, and the ingenuity to make use of to-hand artefacts, tools and resources to illustrate points of difficulty can be helpful [e.g. Tutor D - Section *Learning as doing - Drawing upon resources*]. We have seen how tutors draw upon the expertise of more experienced tutors (e.g. Tutors F & H - Section *Learning as belonging - Old timers supporting newcomers*] and learn by example how to work with students in a support centre.

Perhaps for the first time in their academic lives, the tutors can be faced with uncomfortable challenges. These may be mathematical because they are faced with trying to help a student with an advanced mathematics degree module of which they have no knowledge or experience. Or, they may be faced with problems arising in unfamiliar areas (economics, bioscience, engineering). Challenges can also arise because some of the students seeking help are not particularly able mathematically; they may have weak mathematics backgrounds of which the tutor is unaware. There is increasing awareness within the mathematics support community of the need to support students with specific learning differences such as dyslexia, dyspraxia and Asperger syndrome (Trott 2015). Neurodiversities such as these can increase levels of stress and anxiety when students are faced with the requirement to learn mathematics at university which, in turn, bring particular issues to the fore in a mathematics support centre. The tutor must learn how to deal with these new challenges and with students having different backgrounds and motivations for studying mathematics. We have seen that in these situations of unfamiliar territory the tutors learn to draw heavily on the resources that the students themselves provide (their own lecture notes, their lecturer's notes) [e.g. Tutor E – Section *Learning as doing - Drawing upon resources*] and to work with the students so that they, the tutors, too might undertake the same learning journey. It is at this stage that the support of the community becomes particularly valuable. The tutors can seek help from their partner tutor in the centre, particularly when they are more experienced or have specific knowledge pertinent to the problem in hand. We have seen how tutors work together in a joint enterprise to come to a solution for the student [e.g. Tutors B & H - Section *Learning as doing - Working with students*]. We have seen how they come to recognise the skill sets of their peers, developing tools to assist in this [e.g. Tutors A,B & C - Section *Learning as belonging - Drawing upon each other*] and later draw upon these whilst in the centre.

Within the context of this study, belonging to a large and diverse community of mathematics support tutors was a distinct advantage which helped in numerous ways. Tutors learned to seek help by sharing problems outside of the centre but within their shared office environment, and in turn they offered help to others (e.g. Tutors A & H - Section *Learning as belonging - Outside the centre - and still learning*). This environment not only enabled improvement of the tutor's own mathematical and pedagogical skills, but provided a forum for sharing more general concerns, for being pre-emptive, and for dealing with contingencies. The group had a collective confidence to raise issues with the centre manager [e.g. Tutor G - Section *Learning as belonging - Using the community to work together to resolve tensions*] and to proffer solutions. Moreover, several tutors had their awareness raised sufficiently through this work to suggest improvements to university mathematics teaching and departmental practices [e.g. Tutor D - Section *Learning as becoming - Skill development*]. It is apparent that collectively the postgraduate tutors possess a great deal of intelligence concerning the operation of and the practices in the centre and the nature of the problems which students present, that could be mined to inform improvements to the teaching and learning of mathematics throughout the university. Tutors I and B in Section *Learning as becoming - Skill development* made incisive and poignant remarks in this respect.

We have seen how tutors can refer to themselves as "not being a very good tutor" (Tutor E in *Section Learning as becoming - Becoming better at maths teaching*) or to others as "being really good at teaching people" (Tutor F in *Section Learning as belonging - Old timers supporting newcomers*) and how they are able to reify these notions into sets of characteristics which ought to be avoided or adopted. We have been able to demonstrate numerous instances where tutors' identities as teachers are transformed as they progress through their working lives in the centre.

Negotiation and collaboration in this endeavour have come to the fore through our analysis. We have seen this in way that tutors discuss with each other how to practice in the centre, how workloads are distributed, how they use each other's skill sets, how they alert each other to situations likely to have consequences in the support centre such as coursework deadlines. The nature of this negotiation and collaboration is clearly very supportive with numerous instances of joint endeavour in the solution of problems. 'Old timers' have demonstrated repeatedly their willingness to assist newcomers both practically and affectively. Amongst the self-reported impact on individuals we can cite: improved confidence particularly when dealing with unfamiliar mathematical problems; improved communication skills, including the ability to work with non-specialist users of mathematics.

Our analysis using the lens of communities of practice has enabled us to look systematically at the ways in which the postgraduates learn to tutor. To-date there is but a small number of studies that use the framework offered by this theory to research aspects of university level mathematics education. Those that do highlight the existence of multiple, (sometimes) intersecting communities (researcher mathematicians, mathematics educators, postgraduates, undergraduates). In contrast, the study described herein concentrates on enculturation into and maintenance of a single community albeit one which, as we have seen, exhibits phenomena at the boundaries with mainstream university teaching practices. As noted by Biza et al. (2014) a substantial part of the existing research focuses on proof and the way in which undergraduates must be enculturated into new ways of thinking mathematically. However, as Biza et al. (2014) point out, not all undergraduates aim to become mathematicians. Moreover, there is evidence that many become alienated from university mathematics as their degree course proceeds (Brown et al. 2005). As such there are aspects of the theory of communities of practice, such as that of legitimate peripheral participation (Lave and Wenger 1991) which do not fit well with some characteristics of the undergraduate community. Nevertheless, community and a sense of belonging can act to counteract alienation as explored further in Solomon and Croft (2016). Relatedly, Solomon et al. (2010, p422) demonstrate how a mathematics support centre initially aimed at supporting engineering students "provided the impetus and resources for the generation of a mathematics undergraduate community of practice". Our study, on the other hand relates to postgraduates. For this group we can assume that they aim to be involved in research mathematics. We can see them as legitimate peripheral participants in the community of the researcher mathematicians, though this is not directly relevant to their evolving role within the mathematics support centre. Thus a novel contribution of the work we describe here is the application of the theory of communities of practice to explore and understand the role that postgraduate tutors play within mathematics support.

In conclusion, our data has demonstrated that postgraduates do learn to develop as tutors in a mathematics support centre and through collective encouragement, networking and sharing of expertise can learn to become better tutors. We have shown that tutors perceive their sharing of expertise has impacted upon their practices and consequently the evolution of the centre. It is known that the students on the receiving end of their support and, as a consequence, the University, benefit from their expertise and enthusiasm (Grove et al. 2019b) and as such the tutors contribute to a thriving community of mathematics learners. Moreover, there are substantial benefits for the tutors themselves in terms of improved mathematical and pedagogical knowledge and skills, transferable skills of teamworking, communication and empathy, and a widening of their career aspirations.

## Recommendations

We noted earlier that this research is use-inspired and firmly based in Pasteur's quadrant. We have been able to combine the analysis of the data presented here with knowledge and experience based on developing policy and practice in the field of mathematics support throughout the UK. Attention is now turned to the recommendations that we have been able to draw and suggestions for further lines of enquiry.

### Implications for Tutor Training

This analysis has shed light on the way that training for postgraduate tutors might evolve in order that they are enabled to do their job more efficiently and professionally and ensure that students seeking help get the best learning experience possible.

It is well-documented that identifying suitably qualified staff who can help students *at their level* is a challenge (for example, Starkings 2002). Sutherland and Dewhurst (1999) express concern that university lecturers are not always the best people to be undertaking additional mathematics teaching and support, especially for mathematically weaker students, and by extension this concern might well apply to postgraduate mathematicians too. As Fitzmaurice et al. (2016, p14) note "as tutors are students' first exposure to mathematics learning support it is important that they are trained in order to make their centre an environment that should be welcoming, supportive and non-threatening". So it is all the more important that the training of tutors should attempt to mitigate such concerns.

However, in this paper we have demonstrated that the real learning acquired by postgraduate tutors goes on, not in a one-day training session at the start of their career, but in the learning that is situated in their experience of participation in the life of the centre. Tutor training needs to evolve to reflect this. Our recommendations are based on the following findings emerging from the data analysis:

- To a large extent tutors' prior experiences shape the way they begin to practice. However, we have cited instances where practice needs to change as tutors begin to appreciate that their approaches are not always achieving the desired results, as in the case of Tutor G in Section *Learning as doing - Working with students* whose own approach, whilst advanced, was not appropriate for the student being helped, and had to be modified accordingly. Tutor E in Section *Learning as becoming - Becoming better at maths teaching* became aware that at first he wasn't very good at "hiding the answer" but with time developed alternative strategies that concentrated more on the student's understanding.
- Proponents of mathematics support argue that it should be the student and their requirements that are the primary foci of activity in the centre. Thus it is important to know what stage of study the student is at, what is their primary discipline of study at university and whether they have particular learning differences or, in some cases, anxieties. It is apparent that whilst some tutors make an attempt in this direction [e.g. Tutor I in Section *Learning as doing - Working with students* who recognised that the ways things are done in a mathematics department is always rigorous and formal and that this approach might not be appropriate or necessary for other student groups] others see the mathematics problem itself as being interesting and important [e.g. Tutor D, Section *Learning as doing - Working with students* who really tries to focus on the question itself] and consequently direct attention to that.
- We have seen that tutors attach value to participating in a community with other tutors and draw extensively upon their expertise [e.g. Student H in Section *Learning and belonging - Drawing upon each other* who when faced with a problem from the unfamiliar territory of dynamical systems was able to access support from more knowledgeable colleagues]. Electronic and paper tools to share knowledge, facilitate and encourage networking have proved invaluable [Tutors A & C Section *Learning as doing - Working with students*]. Clearly such expertise is dynamic – changing as tutors' experience grows both in the centre and more widely through their research and other teaching activities.
- It is clear that the old-timers possess knowledge of use to newcomers and are willing to share this. Partnering has proved helpful in several instances cited [e.g. Tutor A in Section *Learning as belonging - Outside the centre - and still learning* who noted that "*a fourth year* [tutor] *comes along whose been doing this a long time and has probably come across that problem themselves*" and Tutor H*:* "*you can copy things you really like that they do*".

So the most significant recommendation we can make would be that a one-day training session at the start is supplemented by an on-going set of regular continuing professional development opportunities in recognition of the fact that most learning is situated in practice. These opportunities would be intended to capture the dynamic nature of the learning that is taking place and specifically address the following points. They would:

- encourage tutors to periodically reflect on their own developing skills - mathematical and pedagogical – and be persuaded to share this information with other tutors.
- encourage tutors to share, in an open and constructive way, how they attend to the individual learning needs of students so that more emphasis can be placed on making the learning experience of those visiting for help more student-centred.

- ensure that it is not left to chance that a newcomer observes some characteristic of good teaching developed through experience by the old-timers.
- ensure that mechanisms are put in place so that tutors are aware of the skills of others and are encouraged to make use of these.

We recognise that making this change has financial resourcing implications and requires additional commitment from the tutors themselves. However, if the centre is to make best use of the talents of its tutors we believe these are fundamental steps in developing excellence. This particular centre is in the fortunate position of having a healthy number of tutors and it is natural therefore to seek to take advantage of the community structure, its various levels of experience and wide-ranging expertise. We believe these recommendations are transferable to other institutions where multiple tutors work.

## Implications for the Centre and Directions for Research

We now draw attention to three areas in which more work is required in order to build upon this body of knowledge and understand how students from all disciplines requiring mathematics can be better supported.

Firstly, we have noted that in its early days the centre attracted proportionally more users from outside the discipline of the mathematical sciences. In later years mathematics undergraduates have become the main users and their usage of this particular centre has recently been explored elsewhere (Grove et al. 2019b). Given the ongoing 'mathematics problem' described in the Introduction and the continued growth of support centres in other institutions, it would not be unreasonable to assume that there are plenty of students in this particular university who would benefit from mathematics support, but who are not taking advantage of it. In the light of the findings by Starkings (2002) and Sutherland and Dewhurst (1999) it is indeed possible the whilst mathematics postgraduates are excellent tutors to undergraduate mathematicians, offering mathematics support to non-specialist students requires a different skill set. Who are the people best-qualified to tutor in a mathematics support remains an important open question.

Secondly, although targeted at students of other disciplines most providers of universal mathematics support report that mathematics students are the major users, notwithstanding the fact that the raison d'etre for most centres was the support of non-specialists. These students are sufficiently well-qualified mathematically to have been admitted to a mathematics degree and, unlike students in many other disciplines, *have specifically chosen* to study the subject at university. Why this group makes substantial use of a support centre is intriguing when we consider that departmentally-based learning opportunities (problems classes, personal tutors, workshops) are additionally offered to these students. Solomon et al. (2010) argue that for female mathematics students in particular a support centre offers 'neutral ground' enabling a power shift in the (usually male) tutor:student relationship and enabling one-to-one discussions that would not take place in a formal class. Croft and Lawson (2017) offer their perspective on why mathematics support centres appear to be so appealing to many mathematics undergraduates and suggest, inter alia, that the availability of physical space and its configuration promote collaboration. It appears that many mathematics undergraduates do not wish to adopt a solitary, competitive approach to studying mathematics but instead value the undergraduate communities of practice that support centres can encourage. But this work is insufficiently developed and the field would benefit from a thorough understanding of this phenomenon.

Finally, very little is known about the practices of tutors in a support centre and how they interact with students. The data presented herein provides insight but has been gathered from the perspective of the tutors. Walsh (2017) has attempted to explore this further through analysis of video recordings of three postgraduate tutors working with engineering and science students in a support centre. Whilst clearly a small-scale study, the findings were troubling. Tutors tended to align their practice with that of a traditional lecturing style, i.e. it was very didactical, providing little opportunity for questioning and dialogue. He refers to the tutors lacking various pedagogical skills necessary for high quality learning. Observational studies could reveal much more about what actually goes on and explore what is effective tutoring within a support centre environment. We would point out though that such studies are fraught with ethical and practical challenges. The act of seeking consent to observe student users who drop-in for help as they explain their difficulties and anxieties may well put off many of the students in most need of help.

The recommendations for tutor training along with the research questions we have posed are offered for researchers and practitioners in mathematical sciences and mathematics education to consider as university mathematics teaching evolves to embrace and enthuse future generations of students. Further, this work contributes to a small but growing body of research literature concerned with bridging the gap between theory and practice in university mathematics education at a time when, to quote Artigue in Sierpinska and Kilpatrick (1998), such rapprochement is vital, as the community seeks to respond to significant changes affecting the higher education sector.

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## Compliance with Ethical Standards

**Conflict of Interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

## Appendix: Illustrative Interview Questions

1. The mathematical background of the tutor, their ambitions and their motivation for working in the centre: *give some details about your current research area and stage of study? For how long have you tutored in the centre? What was your motivation for doing this work?*
2. What the tutors know and think about mathematics support: *what do you think is the purpose of a mathematics support centre? Do you think such a service is necessary? As an undergraduate did you ever benefit from something like this?*

3. The practices tutors adopt whilst working in the centre, the ethos of that work and the environment they were helping to create: *when you enter the centre at the start of a session describe what it is that you do and how you conduct yourself; Do you endeavour to find out something about the course students are studying, and if so do you treat different groups in different ways? What do students say to you, and how do you respond? Can you describe your tutoring style? Has this changed through experience? Do you draw upon any tools to help you? To what extent, if any, do you liaise with other postgraduates working in the centre during a session? Can you think of examples? Afterwards, do you ever go away and work on some problem that you faced in the centre? Do you ever reflect on what has happened and whether you might have done something differently? Have you mentored, trained or helped other postgraduates? Can you think of instances where there have been significant challenges, tensions or disagreements and if so how were these resolved?*
4. Tutors' views concerning postgraduates working in the centre; *what do you think are the benefits (if any) of using postgraduates as tutors? Do postgraduates bring anything different to what might be offered by academic staff? What are the attributes of a good centre tutor and have you witnessed any of these? Do postgraduates have a role to play in feeding back findings into mainstream teaching? Are you aware of this being done? Do the postgraduates work together at all? Do you share problems and difficulties? Have you changed your practice as a result of talking to or observing others? Are you aware of skills that other postgraduates have that you do not?*
5. The skills and qualities tutors think they have been able, or hope, to develop through this work: *can you talk about any skills you have developed through this role? Can you think of anything you are better at now as a consequence of this work? Has the role made you aware of any of your shortcomings? Has working in the centre made you consider your own career ambitions?*



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# A8. Developing and embedding inclusive policy and practice within higher education institutions

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# A9. Community perspectives of mathematics and statistics support in higher education: building the infrastructure

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# Community perspectives of mathematics and statistics support in higher education: building the infrastructure

Michael J. Grove[†,*] Tony Croft[‡], Duncan Lawson[§] and Moira Petrie[¶]
[†]*School of Mathematics, University of Birmingham, Birmingham B15 2TT, UK,* [‡]*Mathematics Education Centre, Loughborough University, Loughborough LE11 3TU, UK,* [§]*Newman University, Birmingham B32 3NT, UK and* [¶]*University of Nottingham, Nottingham NG7 2RD, UK*

[*]*Email:m.j.grove@bham.ac.uk*

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**Over the last two decades, mathematics support has, increasingly, been seen by higher education institutions as a vital mechanism for helping students enhance their mathematical and statistical skills, particularly as they make the transition to university study. Several studies have shown the growth of mathematics support across the higher education sector within the UK, Ireland and beyond. Others have demonstrated its impact upon learners. However, few have explored the extent to which mathematics support is embedded within institutions or the extent to which it is likely to be sustainable. Such analyses are important for both the institutions themselves and the many colleagues who are working to develop mathematics support into an area of study in its own right. Here, we report on a survey of 47 institutions offering mathematics and statistics support within the UK. Findings show that, within many institutions, mathematics support is now embedded as part of student-focused institutional support provision. Further, its impacts are increasingly extending beyond those students who access the support: there is evidence that mechanisms are in place for feeding findings from mathematics and statistics support into mainstream teaching and learning and curriculum development. Significantly, the analysis shows that mathematics support offers good potential for sustainability such that the legacy of national endeavours to establish it more widely will continue to exist into the future.**

## 1. Introduction

For over 20 years, the phrase ‘the mathematics problem’ (LMS, 1995) has been used to describe the issues associated with many students arriving at university underprepared for the mathematical demands of their courses, and the associated challenges for those who teach them. While the ‘mathematics problem’ was initially observed within the engineering and science disciplines, evidence from a range of national reports now indicates that it is prevalent across a range of subject areas (see e.g., Croft et al [2015] for a summary).

In responding to this problem, the provision of additional ‘mathematics support’ for undergraduate students is now common practice in UK higher education, and ‘mathematics support centres’ are often the means of delivering such support. The term ‘mathematics support’ encompasses activities, facilities and/or resources provided to support and enhance students’ learning of mathematics or statistics while the student is enrolled on a programme of study within higher education. Such learning support is extra, non-compulsory and is designed to assist students in developing their mathematical and/or statistical confidence and skills.

Although mathematics support may have had its origins in supporting engineering and sciences students beginning their studies in higher education, it can in general be available to students from any discipline and at any level including postgraduate: *Postgraduate courses, which are often more quantitative than their undergraduate counterparts, give rise to further challenges.* (Tolley & Mackenzie, 2015). Further, employer numeracy tests are an increasingly important part of the employment process: ... *after leaving university many graduates will find themselves faced with numerical reasoning tests when competing for jobs. Yet only 16 per cent of undergraduates studying subjects other than maths have an A-level in maths under their belt. Often they will have forgotten much of what they once knew, and even if they haven’t, their confidence in their own abilities may be low*. (Willetts, 2013).

While there are variations between institutions in their approach to providing mathematics support, the term ‘mathematics support centre’ is usually taken to mean a dedicated, physical space in which mathematics support is offered. While centres may offer a range of self-help learning materials and space for peer-peer learning, an almost universal feature is the availability of a tutor (or tutors) in the centre at specified times for one-to-one or small group advice. Since 2000, there has been visible growth in the existence of such centres within UK higher education. In 2001, a survey undertaken by Lawson *et al.* (2001) identified that 46 out of 95 responding institutions offered some form of additional support for those learning mathematics; by 2012, Perkin *et al.* (2012) reported that this figure had increased to 88 out of 103 responding institutions.

There exists further evidence indicating mathematics support is becoming more widely embedded as part of institutional policy and practice. A recent survey undertaken by Tolley & Mackenzie (2015) sought to establish the views of senior management within UK higher education on the mathematical and statistical support needs of their institutions. Their report identified that a senior manager in every university questioned stated that students in their university had issues with their learning of mathematics and statistics and *that unless they provide appropriate forms of learning support for mathematics and statistics, it is inevitable that there will be an adverse impact on their students’ satisfaction, retention, achievement and employability*. Further, and very much reinforcing the observations of Kyle (2010) *mathematics support is now more visible and high-profile within HEIs and is seen as important for enhancing the student experience and aiding success* (Tolley & Mackenzie, 2015).

While there is much practitioner activity relating to mathematics support, and emerging recognition from senior management of its importance, how it is delivered and managed varies enormously across the sector. This is an area that merits further study, particularly as higher education within UK is undergoing a period of change. The 2017 Higher Education and Research Act 2017 (DfE, 2017) commits to replacing the Higher Education Funding Council for England (HEFCE) and the Office For Fair Access (OFFA) with a single sector regulator and student champion called the Office for Students, and the implementation of the associated Teaching Excellence Framework (TEF) has just entered its third year. As a consequence universities are being increasingly required to articulate their commitment to ensuring fair access and their efforts to ensuring all students receive a higher quality learning experience; mathematics support can be a contributor to both (Matthews *et al.*, 2013).

The publication of the 2010 Independent Review of Higher Education Funding and Student Finance (Browne, 2010) signalled the start of a changed financial environment for higher education within UK with students themselves making an increased contribution towards the costs of their education. In this new era the national, and additional, financial support that was once widely available to institutions from HEFCE (Trowler *et al.*, 2013) to support learning and teaching enhancement and innovation activity has been substantially reduced. Mathematics support was a significant beneficiary of such funding from HEFCE, firstly through the Centres for Excellence in Teaching and Learning initiative (2005–10), then the National HE STEM Programme (2009–12), and most recently a direct activity grant (2013–16). With the removal of this external financial support and incentivization, there is an increased onus upon higher education institutions to fund mathematics support activity for themselves, and as such, it is timely to try to explore just how sustainable the existing range of provision really is.

## 2. Research methodology

In early 2016 an online survey, consisting of 23 questions was undertaken, aimed at those working in mathematics and statistics support, with the purposes of:

- Exploring the roles and recognition of staff involved in providing mathematics and statistics support within higher education.
- Identifying current institutional practices and approaches in relation to the availability of provision, delivery and management of mathematics and statistics support.
- Reviewing the likely sustainability of mathematics and statistics support as currently established within the higher education sector.

While there already exists a tradition of undertaking sector-wide surveys in relation to mathematics support (see e.g., Perkin *et al.* [2012] and Cronin *et al.* [2016]), here the purpose was to build upon this previous work by seeking to understand the practice of establishing and delivering mathematics support rather than ascertaining the extent of current provision.

The survey was targeted at staff responsible for the day-to-day operation of the mathematics and statistics support provision within their institution. Appropriate ethical guidelines (BERA, 2011) were followed in conducting the research: its purpose was made clear at the outset, and responses were received on an entirely 'opt-in' basis. While personal information was collected, this was to assist should further follow-up be required. Any information that might identify an individual has been anonymized in the analysis that follows, and where changes have been made to quotations this is solely for the purpose of maintaining the anonymity of responses; any such changes are shown in [square brackets].

Grove & Pugh (2017) provide a 10-point framework for analysing the potential sustainability of learning and teaching initiatives. The survey questions directly address the 7 (out of a total of 10) indicators on the framework that relate directly to sustainability at an institutional level, and as such, this paper is divided into two parts: the first part presents the findings from the survey, explores their significance and identifies any features of practice that offer benefit to the wider mathematics and statistics support community. The second part then considers these survey findings relative to the framework of Grove and Pugh to explore the current 'sustainability case' for mathematics and statistics support within higher education.

A total of 52 individual responses were received representing 47 higher education institutions within England, Scotland, Wales and Northern Ireland. Of the responses, 51 were from staff members (who formed the target audience for the survey), and so the single response from a postgraduate student was excluded. The multiple responses received from three institutions (including three from a single

Table 1. *Institutional responses presented by mission group (n = 47)*

| Institution type | Number of institutional responses |
|---|---|
| Russell Group | 11 |
| University Alliance | 12 |
| Million+ | 7 |
| Unaligned | 17 |

institution) presented a dilemma for analysis: for some aspects of analysis only institutional responses were required, whereas for others individual perspectives were needed. As such, using author knowledge of the respondents and institutional responses, three of the five entries representing two institutions were removed by data cleaning for the institutional aspects of the questionnaire; two entries remained for one institution as it is known that the university in question operates multiple mathematics support centres delivered by different individuals. As such the number of *institutional* responses equals 48, and the number of *individual* responses equals 51.

## 3. Institutional representation

The institutional responses to the survey are shown within Table 1 and demonstrate wide representation from across the higher education sector. Many universities have formed groups with common interests and these include regional university associations and also so-called ‘mission groups’; these are helpful for classifying responses although some institutions are unaligned with any group. The common ‘mission groups’ have been used: the Russell Group (representing the major research-intensive universities); University Alliance (a group formed of universities based in cities and regions); and, million+ (an association for modern universities). Up until 2013 there existed the 1994 Group which represented the smaller research-intensive universities; had this grouping continued, six institutions currently included as ‘Unaligned’ would have been classified in this 1994 Group.

## 4. Extent of institutional provision

Evidence from Perkin *et al.* (2012) shows that the extent of mathematics support provision within institutions has been increasing since 2002. However, the scale of provision that is available to learners is unclear—that is, how many hours of mathematics and statistics support are available during a typical week in term time? Table 2 shows that mathematics support is typically widely available to learners with over 75% of centres reporting that their provision was available for 10 or more hours per week, and almost 55% being open for more than 15 h per week. In general, there is a clear trend that the longer the centre has been established, the greater is the number of hours of provision made available to learners. The fact that opening hours have increased over the years may be indicative of the value placed on a centre by the host institution; as the centre has matured it has proved its worth.

Many centres also offer support with statistical queries. However, when seeking to explore the current availability of statistics support provision, it is evident that we need a clearer definition of what is meant by ‘dedicated statistics support’ as this led to a level of confusion among respondents:

Table 2. *Availability of mathematics support provision during term time* (n = 48)

| | | (Average) hours provision during term time per week | | | | |
|---|---|---|---|---|---|---|
| | | 1–3 h | 3–5 h | 6–10 h | 10–15 h | 15+h |
| | Length of time institution offering mathematics and statistics support provision | | | | | |
| Offering dedicated statistics support | Less than a year | | 1 | | | |
| | 1–3 years | 1 | | | 2 | 1 |
| | 3–5 years | | | 1 | | 4 |
| | 5–10 years | | | 1 | 1 | 5 |
| | 10+years | | | 2 | 1 | 9 |
| Not offering dedicated statistics support | Less than a year | | | | | |
| | 1–3 years | 1 | | 1 | 1 | 1 |
| | 3–5 years | 1 | | | 1 | 2 |
| | 5–10 years | | | | | 3 |
| | 10+years | | | 3 | 4 | 1 |
| Total | | 3 | 1 | 8 | 10 | 26 |

> I am not entirely sure what is meant by dedicate[d] statistics support. I do offer statistics support to Undergraduate, Postgraduate and Staff but my role is not dedicated to statistics it is for any hidden mathematics within the HE context.

This reflects the fact that statistics support can encompass a wide spectrum: from what might be termed routine problems (determining standard deviation, etc.) up to the design of experimental research studies and subsequent data analysis using sophisticated statistical techniques associated with undergraduate projects and even postgraduate research. Perhaps a better definition to replace 'specialist statistics support' would be 'dedicated statistics support sessions offered by a specialist statistics tutor':

> Statistics support is offered during a specific drop-in session (due to a lack of statistics tutors) and appointments are available upon request.

Of the 29 institutions offering dedicated statistics support (Table 2), 27 made their provision available to undergraduate students. Eleven of the 29 institutions indicated that their provision was available to staff as well as undergraduate and postgraduate students. Providing support to staff highlights one of the perhaps overlooked aspects of mathematics and statistics support and that is its role within the staff development process for those working within institutions. Twelve institutions make statistics support provision available to undergraduates and postgraduates only, and a further three restrict their provision to undergraduates, although the flexibility of support centres in their willingness to support those beyond their target audience was noted in several instances:

> ... can offer to postgrads if time available (we have a limited number of hours given to Stats support).
> We have no remit to offer support to Research Students and staff. However, we do not routinely turn them away when they seek support from us.

Statistics support, given the potential depth and breadth of the queries, means it must be delivered by specialist tutors with specialist expertise and preferably substantial experience in statistics. Additionally, the amount of time spent working on a single query can be significant and while

Table 3. *How is mathematics support delivered within your institution? (*n = *48)*

| | Appointment based | Drop-in | Appointment and drop-in |
|---|---|---|---|
| Delivery modes used for mathematics support | 5 | 14 | 29 |



institutions have models of delivery to reflect this, this has implications upon the extent of the service that they can provide. For example, some institutions offer bookable appointments of up to an hour which means the availability of statistics support to learners is more limited when compared to that of mathematics support.

Almost since the inception of the mathematics support centre, the traditional model of delivering mathematics support within higher education has been through drop-in based provision. Here, students can attend a centre at any time, during its hours of opening, to seek advice on their mathematical queries. Table 3 shows the results from the survey where respondents were asked to identify the main delivery models used for their mathematics support.

It is interesting to note that while drop-in based provision is still highly prevalent, it seems there are many institutions (some 70% of respondents) having some form of bookable support provision for learners. As Table 2 shows, there were 29 institutions participating in the survey who offered dedicated statistics support, but here, 34 institutions reported that bookable appointments formed either a part, or the sole means, of delivering their mathematics support offer; it is evidently the case that bookable provision is no longer restricted for offering statistics support alone. What is not clear here is whether this move towards an appointment-based model reflects the more advanced nature of some mathematical queries, for example relating to specialist mathematics students in their later years of study, whether some support centres are offering their support in more of a tutorial or group format (although some respondents did report they offered this approach), or whether this is to address changed student expectations by providing a guarantee that they will be seen at a particular time or by a particular tutor with specialist expertise relating to their query.

## 5. Locations of mathematics support

When considering the nature of the physical space where the delivery of mathematics and statistics support takes place (Table 4), respondents were able to tick all options that applied to them. A common theme that emerged was how centres are using multiple locations and strategies in order to engage and target students more effectively with the provision that is available:

> Appointments for 1 or 2 students are in dedicated space. Group appointments and Clinics (drop-in) are in different rooms that need to be booked. Most years we have sessions where we go to where the students are but it is not a fixed part of our provision.
>
> Central support is offered in our main library space. College/Department support is offered in college/department rooms.
>
> We have dedicated areas that are open when we are there and are student centred/social learning areas when we are not. We are mobile in the sense that we travel to where the students are and meet with them in social learning environments areas such as cafes across the campus.

TABLE 4. *Locations for the delivery of mathematics and statistics support. Note, here individuals have ticked all that apply which in some instances may be due to multiple locations existing within institutions*

| Dedicated space | Always same place but shared space | Different rooms as available | Mobile | Other |
|---|---|---|---|---|
| 21 | 21 | 14 | 8 | 3 |

TABLE 5. *Where mathematics and statistics support centres with a dedicated space are located within an institution. Note, here individuals have ticked all that apply which in some instances may be due to multiple locations existing within institutions*

| In academic department | Library | Student Hub | Other |
|---|---|---|---|
| 7 | 18 | 8 | 9 |

Issues are known to exist whereby students who are most in need of mathematics and statistics support do not access the available provision. One of the key barriers identified by Symonds *et al.* (2008) was a lack of awareness among such students of the location of the centre or the facilities it may offer. Taking support provision directly to students demonstrates a move towards a more proactive model for the delivery of mathematics support, and this in turn reflects how it is becoming increasingly recognized as an important part of the student support offer of institutions.

In terms of the overall usage of the space made available for mathematics support within institutions (Table 4), the majority of universities who responded reported that they have either a sole-use dedicated space, or are located in a shared-use facility. Again this perhaps is indicative of the fact that institutions are investing strategically in their mathematics and statistics support provision, highlighting findings of Tolley & Mackenzie (2015), or that its visibility (in a regular location) is important for engaging, and indeed reengaging, learners:

> We will shortly be moving to a new, purpose designed space within a new library. This will increase our room size, but it may be used for other things at different times.

For those 42 institutions who reported that their centres had a dedicated location, these appear to be primarily based within other facilities where students from a range of disciplines will be present, for example libraries or student-focused buildings (Table 5). For those that responded ‘other’, centres were based in buildings that were used for teaching, student services or academic skills. This reinforces the point that mathematics support centres are now accessible to students from across a range of disciplines, but also that mathematics and statistics support is now increasingly seen as part of a wider institutional ‘offer’ rather than as an independent or disciplinary ‘service’.

To explore this further, respondents were asked whether they were part of, or working in conjunction with other institutional support or students initiatives: 33 respondents indicated that their provision was integrated or aligned in some way with other institutional services and 15 that it was not. A range of central units were mentioned which had differing names but, in the main, integration was with academic/student skills, learner support/development units or the university library, all of which offered a variety of student-focused services:

> We are part of the study skills service which includes study skills, mentoring, PASS and maths/stats support and share space with these services.
>
> Part of Learning Development which, in terms of its student facing work, also offers Writing and Study Guidance.
>
> The maths team is located as part of a wider Learning and Language support team who contribute to a range of institutional initiatives around student success, employability and learning and teaching.

In some instances, although centres were integrated as part of a central university offering, the partnership nature of this arrangement was clearly articulated:

> We are part of the library professional services team and also have close ties with the School of . . . .
>
> We work with, but are not part of, the academic skills centre, widening participation . . . , Disability Services (I work for this department 1 day a week and we maintain links with them). We also work on projects with the Students' Union and a variety of academic and non-academic departments.

It was evident that some centres had either recently become more closely aligned with other institutional services, or that this is likely to take place in the future:

> just moved to be managed within the library.
>
> Currently in discussion over future provision with central services.
>
> This is likely to change in the future, as there [are] plans for Maths Support to be part of a planned [centre] which will incorporate all student support mechanisms.

The level of integration, collaboration or alignment with other institutional services, again reinforces findings from Tolley & Mackenzie (2015) that institutions are becoming more strategic about how their provision of mathematics and statistics support operates, and as such are now viewing it as an increasingly important part of the student support provision that an institution offers.

With the emergence of a range of new technologies being used within teaching and learning, respondents were asked whether they offered online or virtual mathematics and statistics support to explore whether the delivery approach might have changed beyond the key relationship of a tutor working either one-to-one, or with small groups of students. In their responses 31 institutions indicated that they offered some form of online or virtual provision. In many cases this was of a passive form, making resources available either online or through a virtual learning environment:

> We have a wiki page and a series of online questions.
>
> We have lots of bespoke online resources which are freely available, we have a rudimentary online course.

In others, there were instances of social networking tools being used to provide mathematics and statistics support such as Facebook to enable online discussions:

> We have a Facebook group for maths/stats support in the Department . . . .
>
> We have a . . . Facebook page, which is a new development since September 2015.

For other respondents, there were more interactive forms of remote support offered, either via email, telephone or Skype. Particularly, reference was made to this form of support for either statistics or for those on distance learning programmes:

> We offer some guidance via our webpage and offer Google hangout sessions for students on placements or those who are unable to make it to campus for a variety of reasons.

> Statistical advisory appointments can be accessed via Skype.

> Generally, it's statistics help when online support takes place. Students can email their query to the stats support tutor.

In another institution the online service 'Howcloud' is being trialed to provide asynchronous support to students to allow them to access video, text and annotated tuition.

However, as noted by one respondent, the extent of student engagement with virtual forms of support is not always high, and as such this itself is perhaps an area that merits further study:

> We offer email support and also we offer skype support, aimed at distance learners, however this hasn't been utilised at all.

This emergence of, or at the very least an exploration of new ways of, delivering mathematics and statistics support, is perhaps not surprising for several reasons. There is a new generation of staff involved in mathematics support (12 out of the 51 survey respondents indicated that they had been working in mathematics support for 3 years or less) who may have themselves engaged with technological approaches during their own studies, and as such are exploring how this might be incorporated as part of their own teaching duties. Additionally, students, as well as being more technologically able and so perhaps expecting to make greater use of new technologies in all aspects of their studies, increasingly want support 'around the clock' and this is exemplified by the 24 h opening of some university facilities, particularly around examination time. Conversely, given that online support for teaching and learning has now been around for quite some time, it might seem surprising that just over a third of institutions responding to the survey do not have such a presence for their mathematics and statistics support activities.

## 6. Management oversight of mathematics support

We have already considered the extent to which mathematics and statistics support now appears aligned with other institutional services, for example student support or academic skills. While 33 respondents indicated there was a level of integration, it was not always clear who had the management responsibility for the mathematics and statistics support provision itself. In questioning respondents specifically on this aspect, of the 48 responses received, 29 indicated that their mathematics and statistics provision was a central institutional service, 13 indicated management responsibility rested with an academic department and 6 indicated 'other'. For those who indicated 'other', this was typically because there was some form of joint working between an academic department and a central institutional service:

> We have a partnership model. The Library manage the staffing and facilities, the School of Mathematics provides academic expertise.

> Mixed. Finance provided by [learner support unit]. Day-to-day running organised by Maths group in School of [removed]. Annual report required by [learner support unit].

For those centres that were managed by a central university service, while the name of this service unit varied greatly between institutions, it was typically associated with a student focused service and examples included: the library, academic skills, student (learning) support and student services.

Again it was noted that, in addition to central support, there were instances of departments who provided their own mathematics and statistics support provision:

> There is a centrally funded and managed service, but there are also a couple of disciplines who fund and organise their own support.

Table 6. *Are there governance and reporting arrangements in place for your centre? (n = 48)*

| | Yes | No |
|---|---|---|
| Length of time institution offering mathematics and statistics support provision | | |
| Less than a year | 0 | 1 |
| 1–3 years | 3 | 5 |
| 3–5 years | 4 | 5 |
| 5–10 years | 7 | 3 |
| 10+years | 7 | 13 |
| Total | 21 | 27 |

> The [faculty] manages it's [sic] only support as this was set up as part of the HE STEM project.

Given these management arrangements, the associated reporting and governance processes and structures were also explored (Table 6).

Perhaps surprisingly there were more centres without clear governance and management processes/structures in place (27 centres) than with such arrangements (21 responses). Where formal procedures were not in place, there was recognition that this may change in future:

> nothing currently but I expect that to be formalised soon.

> We are trying to develop reporting back to Schools whose students use the service, but this is not yet fully in place.

Where some centres acknowledged there were not formal arrangements, there were indications that instead there existed some form of informal reporting arrangement:

> There are occasional reports to PVC and also to the [advisory board], but that is concerned with much more than the maths support.

> I've seen some mentions in academic committee minutes but there is no direct interface between maths/stats support and the university's internal committee/decision making systems.

> We have a networking group that we meet with who we feed back to on [support centre] activity. There isn't a steering or advisory group.

The interesting finding here, however, is that almost two-thirds of centres who have been established for more than 10 years do not have formal government or reporting arrangements in place. Perhaps one reason for this is that centres over 10 years old are perhaps not attracting the same level of institutional attention as when they were first established; as a centre becomes a more accepted part of the established infrastructure the need for a steering or advisory group becomes much less. The following anecdote does indeed raise the possibility that when centres are deemed to have 'proven their worth', they perhaps receive less management attention and reporting/governance arrangements are relaxed:

> Had advisory group when setting up in 2002. Now have discussions with head of [unit with responsibility for support provision]. Brief report required by [that unit] (written by me).

In the case of two slightly newer centres (5–10 years old) this also may also be emerging:

> There had been a steering group during the pilot phase of the Centre. In the last two years, some reporting had been made to the university's teaching committee. The future is uncertain as to whether this specific format will continue as it is not deemed necessary.

> Reporting not as substantial as start when we reported to the PVC via Learning and Teaching Sub Committee. Now it is part on a summary report for Student Services Department.

While the relaxing of formal reporting and governance processes can reflect the success and professionalism of the centre in delivering a service, it can have its downsides. There are particular issues associated with building collaborations and generating buy-in from across an institution and with securing longer-term funding and staffing resources. A further issue is when it comes to championing the case of, and achieving recognition for, the individuals who are working to provide a high-quality service—if senior management are not aware of the endeavours of those providing front-line mathematics support, accessing institutional reward and recognition mechanisms can be much more difficult.

Considering those centres that had in place clear reporting and governance structures, there were instances of reporting taking place as part of a much wider process:

> The Student Learning Service writes an annual report on its activities which include maths support. The annual report is forwarded to the hierarchy [Removed but equivalent to Head of Academic Practice Unit and Pro-Vice Chancellor for Teaching and Learning].

> We had a steering group for the first year - reported to them 3 times. The [service unit with responsibility for the support] reports to one of the University committees - the maths support provision is included.

> Maths reporting is completed as part of the wider reporting on academic skills support provided by the institution.

In terms of the actual mechanism by which reporting took place, this was typically through either a written report that was submitted within the institution, verbal reporting to an individual (Pro-vice Chancellor or Associate Dean) or a report to a university committee. In one institution, reporting arrangements for the centre were aligned with key institutional indicators:

> We produce and [sic] annual report focusing on some Key Performance Indicators (KPI) as well as reflecting on the year and planning for the next. We used to have a steering group and then an advisory group. We are in the process of formalising the KPIs more in line with 'sister' services e.g. Careers.

Given management arrangements for mathematics support were found to be largely resting outside of academic departments, respondents were asked whether there were mechanisms in place to allow any findings emerging from mathematics and statistics support, for example common misconceptions within a particular cohort of learners, to be communicated back to their departments so that they might feed into mainstream teaching and learning (Table 7). This is of particular importance as mathematics support can play a strategic enhancement role within institutions. It provides a way of identifying specific issues that may impact upon the student learning experience, for example if a

TABLE 7. *Are mechanisms in place for feeding findings from mathematics and statistics support into mainstream teaching and learning?* (n = *48)*

| | Mechanisms for feeding in findings | |
|---|---|---|
| Formal reporting arrangements in place | | |
| Yes | Yes | 16 |
| | No | 5 |
| No | Yes | 8 |
| | No | 19 |

number of students from a cohort present with similar issues; these issues, if not addressed, may go on to be reflected in subject-level metrics of teaching and learning. Given this, there are real advantages in institutions using their mathematics support provision to identify and drive enhancements at a course or programme level—this will be particularly important if the TEF continues to progress at a disciplinary level.

Responses were equal in number (24 each) for 'having' and 'not having' mechanisms to feed findings into mainstream teaching and learning. Where respondents indicated that mechanisms were not in place this should not necessarily be taken to indicate there were no arrangements; as seven respondents indicated, there are in fact informal processes that can be adopted ranging from conversations, learning and teaching seminars, to a collaborative approach by working directly with the department in question:

> There's nothing to stop me sharing information about maths/stats support with teaching staff and I do so periodically but there is no institutional mechanism for this.
>
> Not directly—but work has been disseminated via LT seminars (this has been driven locally).
>
> There is no 'mechanism' but we would discuss issues within the weekly meeting and agree a reasonable way forward. This may include feeding back to a department and offering to work with them, for instance.

However, it is important to acknowledge here that in such instances, this approach is likely to be down to the work of individual(s) and the contacts they have established through their endeavours. Should they leave their mathematics support duties, there is a risk that this collaborative approach may be lost.

What was particularly evident when analysing responses to this question was that where formal reporting arrangements were in place, mechanisms to feed findings into mainstream teaching and learning were more prevalent which is perhaps no surprise given the ready-made nature of reports and summaries. Where academic staffs were involved in delivering mathematics support, the mechanisms for informing mainstream teaching and learning are fairly self-evident:

> A key strength of our Departmental level support is that it's staffed by the lecturers who deliver the relevant mainstream teaching. We have compulsory data analysis modules . . . So, our Departmental stats support is extremely well integrated into mainstream teaching and learning.

Presentations at a range of institutional events were cited as an important mechanism by seven respondents including annual learning and teaching conferences and organized seminars although as is always the case with such events, there are no guarantees that staff from the relevant department will be present. A much more targeted approach involves direct engagement with the department, either through departmental committees:

> I am able to e-mail lecturers directly and also address [them] in departmental meetings/programme boards

participation in away days:

> findings from successful embedded work has been presented at school away days thus providing academic staff with exemplars of possible ways to embed maths

supporting departments with their curriculum development:

> Involved in the school's portfolio refresh and design of new mathematics module

and contributing to the delivery of departmental provision:

> I am often asked to assist with delivering hidden mathematics guest lectures. These lectures can be informed based on feedback from 1 to 1 student sessions. Using this, we start from where the students are rather than where they think they are or think that they should be.

In one institution a dedicated steering group that oversees the teaching of mathematics to non-mathematicians has been established to act as a mechanism for not only sharing information, but also developing a coordinated institution-wide approach to supporting learners with their mathematics and statistics. Related, there is direct evidence of mathematics support being used to aid, or enhance the work of other institutional units:

> We work in conjunction with [Removed], which provides support for students with disabilities and specific learning differences.

This reflects some of the mathematics-specific issues associated with supporting students with disabilities and specific learning differences (Cliffe, 2015; Trott, 2015) that mathematics support has, over the years worked to address, and that it is now sharing more widely.

## 7. Sustainability

Through the work of sigma significant external support, include financial, has been made available to help institutions establish their mathematics and statistics support provision. For example, through the National HE STEM Programme 22 new mathematics and statistics support centres were established, and through sigma's most recent direct funding from HEFCE provision has been established at a further 10. The important question is, therefore, whether this provision will now be sustained since the external financial support provided by sigma ended in July 2016.

While sustainability is most likely be an issue associated with the end of external funding, even for established centres, longer-term funding concerns may never be too far away. Of the 48 institutional responses received for the survey, 19 were from centres established by sigma since it commenced its activities in 2005.

Overwhelmingly (Table 8), respondents indicated that they felt their provision would be sustainable, and this was independent of how long their institution had been offering mathematics and statistics

TABLE 8. *Likelihood of mathematics and statistics support being sustained in responding institutions* (n = 48)

| | | Established—likely to continue for foreseeable future | Funding needs be negotiated each year | Funding in place for fixed period (>2 years) | Imminent danger of closing | Other |
|---|---|---|---|---|---|---|
| | Length of time institution offering mathematics and statistics support provision | | | | | |
| Sigma support to establish new mathematics support provision | Less than a year | | | 1 | | |
| | 1–3 years | 4 | 1 | | | 1 |
| | 3–5 years | 2 | | 1 | | 1 |
| | 5–10 years | 6 | | | | |
| | 10+years | | 1 | 1 | | |
| All other (non-sigma established) centres | Less than a year | | | | | |
| | 1–3 years | 2 | | | | |
| | 3–5 years | 4 | | | 1 | |
| | 5–10 years | 4 | | | | |
| | 10+years | 14 | 2 | 1 | 1 | |
| | Total | 36 | 4 | 4 | 2 | 2 |

support. Several respondents indicated that they were aware of the support of senior management for their work, but this was in no way universal. It appears that the positive views of senior management towards mathematics and statistics support, as expressed within the work of Tolley & Mackenzie (2015), may not be reaching those who are actually providing the service to learners.

While such findings relating to the suitability of mathematics and statistics support provision are clearly positive, there is clearly a need for caution. Some respondents cited that there remains an annual challenge to secure funding to maintain their centre, and highlighted uncertainty if this ceased:

> Have support from the Institution to further embed maths and stats support, in principal agreed for at least 2 years . . . We only got this as I got fed up with the annual negotiation for funding and refused to continue in this manner next academic year. The annual negotiation reduced staff morale and dedication to this service (as we seem to have been permanently short staffed since setting up the maths support centre).

> We are funded by Widening Participation. I am not sure what would happen if we no longer received this funding.

Others noted that there were limits to what could be achieved with the level of funding they currently have available:

> The funding is quite small, so this can be a limiting factor in expanding the provision.

This will be particularly important if the uptake of mathematics and statistics support by students continues to grow, and how their expectations as to the level and quality of service they may have come to expect can be reasonably managed.

While the nature of the responses from the 47 higher education institutions (and 48 centres) indicates a very positive story, with 75% of respondents reporting their centres are likely to continue for the foreseeable future, there were a number of institutions who indicated that funding negotiations need to take place on either an annual or bi-annual basis. More worryingly, however, there were several responses which indicated that the critical role of staff members as the key providers of mathematics and statistics support is perhaps not being considered. Several responses indicated that some institutions were looking to reduce costs by cutting staff:

> The University is making redundant most of the staff teaching mathematics who incidentally is the only staff grouping that serves in the maths/stats support centre.

> Having dealt with a record number of students last session it was a surprise to find my FT post placed at risk and then replaced by a 0.4 FTE post.

Clearly, sustaining any form of mathematics support provision requires a level of ongoing financial resource, but it is very much the case that not everyone, even if they have a strong mathematical background, is suited for providing this support (Croft & Grove, 2016). As such, institutions, if they are to maintain a service that meets the needs and expectations of learners must ensure they engage staff with not only the necessary subject knowledge but also the skills and expertise to work with learners who may be among some of the most vulnerable within an institution. Cutting specialist mathematics and statistics support staff is a false economy and can cause serious problems for managing student expectations and their satisfaction.

## 8. Applying a framework for sustainability to mathematics and statistics support

Following an analysis of the projects and activities undertaken through the National HE STEM programme, Grove & Pugh (2017) have identified a framework of 10 indicators which they suggest can be used to identify whether an activity is likely to be sustainable after its initial 'pump priming' funding ceases. While it is clearly the case that any activity will require some form of investment (financial or human), this framework was designed with a single project or activity in mind; here, in the case of mathematics and statistics support we have a wealth of national activity undertaken over the last 10 years, much of it supported in some way through the work of sigma (Croft *et al.*, 2015).

While the framework can be applied to individual centres, it is more appropriate to explore the broader question of whether mathematics support, as a shared activity across the higher education sector, can be sustained. This exists in two parts: the practice and provision of mathematics support as led by higher education institutions, and the scholarship of mathematics and statistics support as led by the individuals who work within it. Such an analysis is timely as one of the key requirements for sigma, following its most recent 3-year activity grant from HEFCE, has been to embed a sustainable portfolio of mathematics and statistics support activity across the sector.

Grove & Pugh (2017) note that sustainability is realised when one, or more, of three possible outcomes are achieved: (1) The activity continues unchanged in its current form; (2) An institutional decision results in the activity being embedded or continued in an alternative form or (3) Staff are equipped with a new outlook or skills that they continue to deploy throughout their careers. Here, we consider seven of Grove & Pugh's (2017) indicators that relate specifically to the institutional aspects of sustainability. They allow us to explore whether the senior management commitment for mathematics support, as noted by Tolley & Mackenzie (2015), is validated by those working to deliver this support within institutions. The remaining three indicators, relating to sustainability through the influences, activities and scholarship of the individuals involved in mathematics support, will be considered in a future work arising from this study.

### *8.1 Embedding the importance of sustainability at the outset*

Of the 47 higher education institutions (and 48 mathematics and statistics support centres) sampled within this survey, 18 of them had received support (financial and guidance) from sigma to establish their mathematics support provision; a further five received support to enhance their existing provision. In particular this funding was made available as part of either the sigma CETL initiative (2005–2010), sigma's work in the National HE STEM Programme (2009–2012) or most recently as part of its HEFCE individual activity grant (2013–2016).

Funding was awarded as part of a competitive process where those submitting proposals had to secure senior management support and explicitly articulate how their activities would be sustained after core funding had ceased; additionally, institutions were required to commit a matched-level of funding as part of their commitment. Exploring the response to the sustainability question for the 19 new centres established by sigma yields the results shown in Table 8.

Overall, just under two-thirds of the sigma-established centres indicated that they were likely to continue for the foreseeable future (and none indicated they were in imminent danger of closing), and this was almost identical to the figure for the non-sigma established centres (which was exactly two-thirds). The key difference, however, is that sigma-established centres are typically much younger than the non-sigma established centres. While it is to be expected that more mature centres will have proved their worth within an institution and as such are more likely to be sustained, among newer centres this is a positive finding. It reflects not only the requirements of sigma for institutions to consider sustainability when bidding for a centre, but perhaps also in the value now placed upon mathematics and statistics support by institutions and as articulated by Tolley & Mackenzie (2015).

### 8.2 Proven starting point

Mathematics support is not only well established, but the extent of provision has continued to grow over the last 10 years (Perkin *et al.*, 2012). Much work has been done on how to set up a support centre (see e.g., Mac an Bhaird & Lawson, 2012), how to train those delivering provision (Croft & Grove, 2016), how to gather feedback (Green, 2012) and how to evaluate institutional mathematics and statistics support provision (Matthews *et al.*, 2013). There are now also many different models and approaches for individuals to adopt and utilise (Marr & Grove, 2010). Additionally, there are many freely available, high quality, mathematics and statistics support resources available on sigma-supported websites such as mathcentre and statstutor which can be used as the basis for establishing support provision.

The resource base for anyone looking to establish or develop their mathematics and statistics support is therefore extremely strong, furthermore as we shall discuss later, there is a large and active community of practitioners willing to support others with the development of their provision. As an example, this was exemplified through the work of sigma where experienced mentors were allocated to help those who were new to establishing such provision:

> Of most use to us was our mentor who was happy to share their mistakes, so we could avoid them and gave practical advice that will give us the best chance of sustaining our mathematics support programme. (Grove, 2013)

Although this scheme was funded and enabled visits between institutions to take place, mechanisms now exist for sharing practices electronically, for example, through the electronic sigma JISCMAIL mailing list.

### 8.3. Up-front investment

In the case of sigma-established centres, funds were made available to pump-prime their start-up by enabling the purchase of equipment and resources; this included direct financial resource from sigma and a level of matched funding from the institution. Furthermore, sigma has put in place a substantial knowledge-base to help institutions establish their provision by building upon the (proven) models and resources of others; by making this freely available, the mathematics support community itself has contributed to the up-front investment for any institution establishing or enhancing its mathematics and statistics support provision.

While there will always be a requirement for staff time, with evidence that some institutions are investing in dedicated staff, it is evident from the results of the survey (Table 4) that institutions are investing in the facilities for mathematics support as evidenced by centres increasingly having a regular and visible presence within institutions. Initial up-front investment appears to involve institutions making available a regular, but shared, location where mathematics and statistics support can take place. Of the sigma-established centres less than 3-years old six out of the seven reported they had the same regular location but that the facilities were shared; for the sigma-established centres over 3 years old, 50% of these reported having their own dedicated space. As such, while there is evidence of up-front investment, through both sigma and the hosting institution, there also appears evidence of ongoing investment by institutions in their mathematics and statistics support provision as it matures.

### *8.4 Alignment of activity with wider priorities*

It is evident from the senior management survey of Tolley & Mackenzie (2015), that mathematics support is now often seen as part of a wider institutional 'offer':

> Decisions related to the development of the provision are often not taken in isolation but as part of wider strategic considerations. In some cases the developments will build upon previous experience and work within existing organisational structures, whereas in others the need to make transformational changes has been acknowledged and priority is being given to developing and implementing plans for university-wide systems of support.

Such findings were reinforced in the survey: it is not only the case that mathematics support centres work in conjunction with other institutional centres (such as student support, academic skills and the institutional library), but they are increasingly embedded as an integral part of this provision and this is further validated through their reporting arrangements. It is also known that many institutions make explicit reference to their mathematics and statistics support provision in their OFFA Access Agreements (Grove, 2013).

### *8.5 Institutional commitment*

In many ways the commitment of institutions to their mathematics support provision can be demonstrated by evidence of how provision is embedded as part of a wider institutional offer. While the findings from this survey are important evidence, it is the views of senior management that are critical. Again as noted by Tolley & Mackenzie (2015):

> Many of the institutions sampled recognise the need to further develop the support they offer and to extend its scope and/or improve its effectiveness

and

> The need for mathematics support across all subjects is a major challenge that all HEIs surveyed regard as likely to continue.

As such, the challenges associated with student learning of mathematics and statistics are well recognized by those making strategic decisions within higher education institutions, and mathematics support itself is clearly seen as a recognized solution. Further, there is evidence that institutions are committing to their activities in this area through dedicated staffing appointments, and there are examples of support centre staff being rewarded and recognized for their endeavours which we will report on in a future work.

### *8.6 Wider value*

Mathematics support centres had their origins in the early-1990s where their primary mission was to support science and engineering students who were struggling with the mathematical skills and knowledge needed to successfully make the transition to university. In the time since, they have demonstrated that they can grow and adapt to support students from a wide range of disciplines and years of study, either at the transition to university, throughout their studies or when supporting those undertaking employer numeracy tests at the transition to the workplace. Further, a number of centres also offer tailored and specialist provision for students who have additional needs and specific learning differences.

Through the survey, centres have demonstrated that their provision has developed and expanded to meet students' needs. At one level, this may be through increased hours of opening. Additionally, many institutions now provide statistics support, and the models of delivering this have developed from the drop-in approach associated with problems in mathematics, to an appointment-based model. The support itself is no longer offered solely to non-mathematicians beginning their university studies; there is evidence that some centres are also supporting specialist mathematics students in their later years of study (Croft & Grove, 2015), and others make their provision available to staff within the institution. As such, it may very well be the case we need to revisit the definition of exactly what constitutes 'mathematics support' as this has clearly broadened. Also, there are signs that mathematics support is broadening still further with many institutions offering some form of virtual support. While in many cases this may be passive, in others, new technologies are being used to deliver asynchronous support to learners based outside the main university campus; with higher education in the UK continuing to itself change, and students seeking to learn 24 h a day and in new ways, this is likely to be a continued area of focus and growth for the mathematics and statistics support community. Mathematics support has demonstrably diversified, and through those involved will continue to do. As such, its value is now wider than that which was originally envisaged during the initial phase of sigma between 2005 and 2010.

### *8.7 Evaluation*

Many of the institutions responding to the survey indicated that there were formal reporting arrangements to convey the scale/impact of their work; for a number of others, even when arrangements were not classified as formal, informal mechanisms were noted as being in place. For those centres whose funding is renewed on an annual basis, it is likely there will be some form of evaluative requirement linked to their funding. As such, evaluation of mathematics support, in some form, is an essential part of the provision for both monitoring and planning purposes:

> All support is logged onto a CRM system, this is a new system by [which] my manager hopes to run reports at the end of the academic year.

> A yearly report of the usage of [the support centre] is created for management with our collected data.

Many individuals have gone beyond evaluating student engagement with their centres to exploring impact upon students and their learning. Not only this, as noted within the survey, examples were presented of how mathematics support is now going on to inform the design and delivery of the wider undergraduate curriculum. In 2012, a review of the research literature relating to mathematics and statistics support (Matthews *et al.*, 2013) highlighted almost 80 published academic works relating to mathematics and statistics support. If such a review was undertaken now, the volume of such works would undoubtedly be greater—mathematics support has become an area of academic study very much in its own right.

*8.7.1 Implications of the framework* Considering the institutionally focused aspects of the framework of Grove & Pugh (2017) for the sigma-established mathematics and statistics support centres yields a very positive case for their longer-term potential for sustainability. In particular, this appears linked to the approach used by sigma when establishing these centres, particularly relating to the requirement that institutions explicitly consider their sustainability at the outset, but also that mathematics and statistics support now forms part of a growing and vibrant national, and indeed international, community. Many of the arguments considered here for the sigma-established centres are also applicable for the non-sigma established centres, and taken as a whole, the evidence does point to an important longer-term role for mathematics and statistics support within UK higher education.

## 9. Conclusion

There exists an increasing array of evidence highlighting that mathematics and statistics support is now widely offered by higher education institutions within UK. The recent work of Tolley & Mackenzie (2015) to gather senior management perspectives on support provision offers insight into the value placed upon such provision by senior management; the findings from our survey reinforce their work. The data show that not only is mathematics support available within a range of different types of institution, as identified by their mission group, but that it is extensive in both its extent (number of hours) and range (backgrounds of the individuals to whom it is available). Significantly, there is evidence that the way in which mathematics support provision is 'positioned' within an institution is becoming increasingly strategic; in many cases there is alignment with other student-focused services and mechanisms are in place for institutions to utilize their findings from offering mathematics support to feed into main-stream teaching and learning. For a number of years there has been much debate relating to the embedding of sustainable teaching and learning interventions within UK higher education; our findings show that the approach adopted by sigma, when establishing mathematics support provision as part of its national activities, in terms of requiring matched institutional support and a clear plan for longer-term sustainability has paid dividends with supported centres showing a high likelihood of longer-term sustainability as perceived by those who lead them. More broadly however, the evidence indicates that mathematics support appears a sustainable part of the teaching and learning provision within UK institutions.

The data from the survey also give an interesting snapshot of mathematics and statistics support and demonstrate that it is itself part way through a transition: what may have started as a cottage industry (Kyle, 2010) has progressed to becoming a respectable academic practice and is now well on the way to becoming a part of the general institutional student support infrastructure in most higher education institutions. The centres represented through this survey are all at different points in their evolution and as such represent a spectrum of mathematics and statistics support provision within the UK from which we can learn. While, like much of UK higher education, they are affected by external factors, the changing educational landscape has helped accelerate their development along with the support of sigma which has not only directly led to the establishment of many new centres, but also has enabled effective practices and ideas to be freely shared.

In this paper, we have focused upon what might be termed the (infra)structural aspects of mathematics and statistics support provision. However, equally important are the staff who work to provide this front-line support. Our survey has also explored the role of these individuals, the recognition and support for their development that they receive from their institutions, and the contribution that they make to the overall sustainability of mathematics support provision. These aspects will be reported in a future work.

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**Michael Grove** (m.j.grove@bham.c.uk) is a Reader in STEM Education within the School of Mathematics at the University of Birmingham. He is a National Teaching Fellow and was Associate Director of the sigma Network for Mathematics and Statistics Support between 2013 and 2016.

**Tony Croft** (a.c.croft@lboro.ac.uk) is a Professor of Mathematics Education at Loughborough University and has developed mathematics support there for many years. He was a Director of the sigma Network for Mathematics and Statistics Support from its inception in 2005 up until the end of its most recent HEFCE funding in 2016. He was a Director of mathcentre, the UK's virtual mathematics learning support centre, and was awarded a National Teaching Fellowship in 2008. He was awarded the IMA Gold Medal 2016 for his outstanding contribution to mathematics.

**Duncan Lawson** (D.Lawson@staff.newman.ac.uk) is Pro Vice Chancellor (Formative Education) at Newman University, having previously been the founding Director of sigma at Coventry University where he worked in mathematics support for over 20 years. He was awarded a National Teaching Fellowship in 2005 and was also awarded the IMA Gold Medal 2016 for his outstanding contribution to mathematics.

**Moira Petrie** (Moira.Petrie@nottingham.ac.uk) is currently Network Plus Manager: Industrial Systems in the Digital Age at the university of Nottingham. Prior to her most recent role she was project manager for the sigma Network for Mathematics and Statistics Support.

# A10. Defining 'sustainability indicators' for higher education teaching and learning innovations

**Grove, M. J.** & Pugh, S. L. (2017). Defining 'sustainability indicators' for higher education teaching and learning innovations. *Education in Practice*, 3, pp. 13–18.

Paper

# Defining 'sustainability indicators' for higher education teaching and learning innovations

**Michael Grove[1] and Samantha Pugh[2]**
[1] School of Mathematics, University of Birmingham
[2] School of Physics and Astronomy, University of Leeds

**Abstract**
Enhancement and innovation have been key aspects of Higher Education development in recent years. Government, professional bodies and individual institutions have committed significant funds to the development of teaching and learning innovation and benefits have been realised across the sector. However, in a changing funding landscape, the cost of teaching and learning innovation will fall on individual institutions to initiate and deliver. Whilst historically, many benefits have been realised from such initiatives, their longer-term sustainability should be examined. This paper firstly seeks to define what sustainability means in the context of teaching and learning innovation. We then examine the landscape for Higher Education teaching innovation and propose a number of qualitative indicators that might be used for a teaching and learning enhancement or innovation project to determine how likely its activities are to be sustainable, in some form, beyond their initial implementation stage.

## Context: Teaching and learning enhancement and innovation in England

Teaching and Learning enhancement and innovation have become common features of English Higher Education. Until recent times, substantial funding for innovation and enhancement activity was made available by the Higher Education Funding Council for England (HEFCE) to universities (Trowler, 2013). With the changes to higher education funding that were initiated following the Independent Review of Higher Education Funding and Student Finance (Browne, 2010), the availability of such funding has been substantially reduced, and now universities are increasingly supporting these activities for themselves. This is exemplified, for example, by the rise in institutions establishing their own dedicated, and academically led, teaching and learning enhancement units (for example the Teaching Academy at the University of Birmingham and the Leeds Institute for Teaching Excellence and Innovation), and the complete removal of funding by HEFCE at the end of July 2016 from the Higher Education Academy, the UK's national body for championing teaching quality within Higher Education.

The Quality Assurance Agency (QAA) for UK Higher Education defines quality enhancement to be 'taking deliberate steps at Institutional level to improve the quality of learning opportunities' (QAA, 2015:32), and although HEFCE has indicated it will continue its investment in learning and teaching enhancement its approach will be guided by an enhancement strategy whereby 'priorities are addressed consistently, with clear leadership, over extended periods of time and with consistent attention paid to long-term sustainability' and that effects 'a culture change across the system' (Trowler et al., 2014). However, this must be considered in the context of a changing higher education landscape within England where the recent Government white paper (BIS, 2016) commits to replacing HEFCE and the Office For Fair Access (OFFA) with a single sector regulator and student champion called the Office for Students, and implementing a Teaching Excellence Framework (TEF). With the TEF soon (at the time of writing) due to report on its Year 2 outcomes, in its most recent phase providers who elected to submit to it have been assessed against three main aspects: Teaching Quality; Learning Environment; and Student Outcomes and Learning Gain. As described by Skelton, it is therefore timely that:

*'We need to forge a productive relationship between teaching excellence and ongoing scholarship. We need a teaching excellence that has sustainability: one that is dynamic, enquiring and reflexive.'* Skelton (2005)

Teaching and learning innovation and enhancement needs to be more strategic in its approach: meeting clearly identified needs; success criteria defined at the outset; rigorous evaluation to capture learning and determine impact; a clear role for students in the process; not just dissemination but wider 'uptake', that is mechanisms to enable the activities, approaches and resources to be directly utilised across and outside of the institutions in which they are developed; and, clear recognition and reward for those involved in excellent practice in teaching and learning.

## Just-in-Time Teaching

As we continue into Year 3 of this new TEF-era, there will need to be greater selectivity in the enhancement activities that are supported. There will be an increasing emphasis on identifying and evidencing those that have a demonstrable impact upon students and their learning, particularly if institutions are able to submit a contextual statement as part of their TEF submission, and if we eventually move, as currently proposed, to a subject-based system of review. Whilst this must not discourage innovation and the trialing of new approaches, it will mean that understanding the impact of one's teaching and learning innovation practices long before results may manifest themselves in nationally available datasets will be vital.

It will also not be enough to trial new approaches activities, real thought must be given to how they might be sustained, or scaled, particularly if they have, or begin to show, the desired impacts. As such, while there is perhaps a clear understanding of what we mean when we discuss 'innovation' and 'enhancement', it is also important to be clear in how we define the constructs of sustainable and sustainability in the context of Higher Education teaching and learning development.

In its crudest sense, sustainability is often interpreted as an activity not requiring any additional financial investment for it to continue, and given the changed financial climate within UK higher education (Browne, 2010), ensuring activities are sustainable, is a priority for all universities. However in practice, this is unrealistic since any activity will require some form of ongoing resource investment in order to be maintained be it financial or more likely human. A definition of sustainability has been proposed (Wiley, 2007) in the context of Open Educational Resources, which considers sustainability as a project's *'ongoing ability to meet its goals.'* This can be achieved in retrospect, but it is also useful to establish if there are indicators at the start, throughout, and at the end of an educational initiative that can provide some indication of whether an initiative might be truly sustainable.

Activities established through national initiatives will typically have undergone some form of external evaluation at some stage during their lifecycle, most likely as a condition of funding. We can interrogate the reports of such projects to explore whether sustainability is considered, at what stage in the project lifecycle, and how the meaning is defined or interpreted. In beginning our analysis, however, there is a need to formulate a common understanding of what we mean by the construct 'sustainability' in relation to educational enhancement and innovation. We can propose that the sustainability of an educational enhancement activity or project is deemed to be realised when one, or more, of the following outcomes is achieved:

1. It continues, in current or modified form, within at least the Higher Education institution(s) initially involved in its development and implementation, after the period of project (financial) support ends.
2. It influences or informs the wider practices of a department, faculty or institution such that it brings about demonstrable changes to existing practices and approaches in line with the ethos of the original activity.
3. It influences and informs the attitudes, beliefs and values of those individuals involved in (or exposed to) the activity such that it changes their own individual practices and approaches.

Such a definition is broad, but the common element is that the activity continues in some form, either directly or indirectly, either through practices that become mainstreamed or institutionalised, or by equipping staff with a new outlook or skills that they continue to deploy throughout their careers. An activity needs to continue for a period of time in order to be judged sustainable (in its original or a modified form). We make no judgement here over what the time period is, as it will vary and indeed the enhancement process for teaching and learning must be a continuous one. We are not at this stage concerned with when we can make a judgement on sustainability, but how we might. Further, if we cannot make a conclusive assessment, are there indicators that might be used to determine whether the activity has 'sustainability potential'; by this we mean are there are supporting conditions in place at the outset that mean it is likely to be sustainable?

**Indicators of 'sustainability' in teaching and learning: A case study approach**

Here we consider one example of HEFCE's targeted approach to learning and teaching innovation and enhancement. In 2004 the Secretary of State for Education and Skills sought advice from HEFCE on strategically important, but vulnerable, higher education subjects or courses (HEFCE, 2005). A review was undertaken to identify subjects in need of support to address an imbalance between supply and demand, and a range of disciplines were identified where participation had been falling steadily over a number of years. In response, HEFCE initiated a programme of work to support subjects deemed strategically important and vulnerable. This included four pilot projects in chemistry, engineering, mathematics and physics designed to pilot and evaluate new approaches to increasing and widening participation in these discipline areas. In 2012 the £21 million National HE STEM Programme initiated a range of interventions designed to designed to enhance the way universities recruit students and deliver programmes of study within the same four STEM disciplines (Grove, 2013); a key feature of the National HE STEM Programme's work was transferring and embedding the learning from these pilot projects more widely so that they became part of the core practice of higher education institutions (HEIs) (Grove, 2013).

The National HE STEM Programme was one of the few initiatives where sustainability was explicitly embedded for consideration during the tendering phase. As a consequence, sustainability was taken seriously throughout the entire Programme:

*'…our judgement is that both in terms of design, and in terms of implementation, sustainability is being taken very seriously across the programme.'* WME (2011)

Given the prominence of sustainability for the National HE STEM programme, during its design, implementation and delivery, it seems appropriate to use it, and its activities, as a model for exploring whether there exist any indicators of sustainability potential within educational enhancement and innovation projects.

It is evident from the evaluation reports of many initiatives, for example the *'Summative Evaluation of the CETL Programme'* (SQW, 2011) that many such evaluations are undertaken as an activity concludes or shortly after it has concluded. This is perhaps understandable: for large-scale activities the infrastructure is in place to support the data collection that is necessary, and often, a judgement is needed as to whether it should continue to be supported post-funding period. However, there are inherent dangers in trying to determine whether sustainability will be realised so close to their conclusion:

*'Robustly measuring sustainability is though inherently difficult when a programme was only just drawing to a close. It is only when the external support has been fully removed for six to 12 months (or potentially even longer) that sustainability can be conclusively demonstrated.'* CFE (2013)

Whilst an activity may appear to be continuing, it could equally be the case that its development is still continuing, albeit without the support afforded through the project, or that insufficient evidence is currently available to make a judgement as to its overall effectiveness and validity in the longer term.

For an activity to be sustainable, it needs to offer some benefit for stakeholders. Such benefits might be identified in the longer-term through evaluation or research, but in the earlier stages could be indicated by the perceptions of staff, students and other stakeholders (albeit sometimes anecdotal) that the activity is offering incremental benefit to a department or institution. Equally, activities might continue to be modified and adapted so that they exist longer-term in an almost unrecognisable form, or even exert a wider influence beyond what was originally intended; here the activities will have a legacy, which may be much harder to determine.

Given such challenges, an appropriate analysis is to explore longer-term potential for sustainability by considering a series of 'sustainability indicators'. These give an indication of whether the environment is conducive to the activity having a high likelihood of continuation beyond the end of its funded period. If so, can these then be used as a proxy measure to infer the overall likelihood of sustainability of an activity?

Through the many activities (greater than 500) of the National HE STEM Programme, we have analysed individual project reports and considered data collected by both external (CFE, 2013) and semi-external (for example Tolley, Greatbatch & Mackenzie, 2013) evaluations of the activities undertaken as the Programme drew to a close. It is natural to treat statements made at project closure, by those who have run successful projects, with caution because there is often a feeling of elation. However, such individuals are often best positioned to identify the potential for sustainability, and are ideally situated to put appropriate plans in place.

Considering the reports and case studies produced through the National HE STEM Programme has enabled us to identify ten factors, or sustainability indicators, that appear to provide an indication of whether an educational activity is likely to be sustainable. These sustainability indicators are likely to contribute to an activity being sustainable in the longer term, and may therefore potentially be used to make a reasonable judgement relating to the sustainability of an activity during its earlier stages. The evidence in support of these indicators, extracted from the individual projects, is contained within the final National HE STEM Programme Final Report (Grove, 2013). The purpose here is not to represent this evidence, but to provide an overview of the indicators and offer suggestions, based upon our experience, of how they might be interrogated and analysed by those who have strategic responsibility for establishing and supporting learning and teaching interventions. This is summarised within Table 1.

## Further work

At this stage we have merely identified potential indicators of sustainability and provided suggestions, based upon our experience, of how they might be investigated for individual projects and activities. It is to be noted that there is a degree of overlap with how they might be evidenced or demonstrated, however, it seems apparent that all indicators can be successfully interrogated by funders through regular dialogue (either through structured written reports or project meetings) with their projects. As such, our initial analysis offers recommendations for the structure and format of interim and final reports and case studies, but most significantly, makes the case that the idea and importance of sustainability should be highly visible to project leads.

At this stage we have not tested whether certain indicators are critical to sustainability or whether a minimum number need to be present, and indeed there is a need to refine our analysis further. This is the next stage of our work which will now be undertaken following the recent (2015) collection of data from these same National HE STEM Projects some three years (minimum) after their external funding concluded.

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Table 1: Sustainability indicators for learning and teaching enhancement.

| Sustainability Indicator | Description | How might this be interrogated/evidenced? |
|---|---|---|
| 1. Embedding the Importance of Sustainability at the Outset | Ensuring that sustainability is seriously considered by project leads during the development stage of an idea and is subject to rigorous (peer) scrutiny. Then, ensuring sustainability is considered and questioned throughout the lifetime of an activity. | ■ Include, within initial proposals and guidance, a section that explicitly asks proposers to highlight how they will sustain/continue their activities.<br>■ Ensure interim reports explicitly ask that project leads address the question 'Describe your current progress towards sustainability?'<br>■ Ensure the final project case study/report template contains an explicit section on sustainability – make this available to project leads immediately upon project commencement, and make them aware that case studies will be made widely available. |
| 2. Proven Starting Point | The development work and learning has already been applied elsewhere, and the opportunity exists to build upon what works and commence the activity from an advanced starting point based upon the knowledge and expertise. Resources may exist, and the value and impact of the activity will often be evident. | ■ Asking project leads to articulate, at the proposal stage, how their work aligns with the existing body of practice, and, if appropriate, how the project will build upon this.<br>■ Similarly, asking staff to articulate the anticipated impact of the activity or intervention at the outset, and then commenting upon progress towards this within subsequent reports.<br>■ Where there is an existing starting point, are the activities undertaken in conjunction with (or with the support of) those with existing expertise or utilising existing resources/materials? |
| 3. Up-Front Investment | Many developmental activities require an initial 'up front' outlay. This may be to develop resources, purchase equipment, or to buy-out staff time. After this initial work, ongoing delivery costs will be lower if there are no consumables costs. The significant resource cost then is staff-time which, if there is perceived to be benefit to an institution, can be allocated to the ongoing continuation of an activity. | ■ To what extent does the proposal request non-consumable resources?<br>■ Are there clear examples and plans for how these resources or equipment will be used? Are their subsequent examples (case studies) of their use?<br>■ How will the resources or equipment continue to be made available and used? |
| 4. Alignment of Activity with Wider Priorities | The activity aligns with a wider set of priorities, for example institutional or national and, as such, provides opportunities for leveraging additional support or commitment. | ■ Encourage project leads to explore the wider context of their work, for example within the context of departmental, faculty, institutional or disciplinary priorities or national/international events. For example, does the activity align with an institutional Office for Fair Access (OFFA) Agreement?<br>■ Seek evidence from senior staff, within the department(s) where the activity is based, of its contribution to the work of the department, including its impact on staff/students.<br>■ Is the activity becoming embedded as part of the curriculum, or departmental/institutional practice? |

| Sustainability Indicator | Description | How might this be interrogated/evidenced? |
|---|---|---|
| 5. Institutional Commitment | Direct buy-in or support is provided by the institution. This may be additional financial resource for development, to ensure on-going delivery, or in-kind support, such as the allocation of additional staff time or incorporation of the activity within workload timetabling. | ■ This extends beyond a senior level letter or statement of support at the outset of the work.<br>■ Solicit, during the proposal stage, evidence of the 'in kind' commitment to the project, both financial and human. Ensure this is validated during interim and final project reports.<br>■ Seek evidence of the (unexpected) 'in kind' contributions made throughout the project by others – how have they contributed to its work?<br>■ How have senior management been engaged in the activities of the project? Senior management engagement has been found to be a key factor in successful implementation/delivery (Tolley, Greatbatch & Mackenzie, 2013). |
| 6. Wider Value | This might also be termed 'transferability': the potential of an activity to extend beyond its initial sphere of influence to be used by others within the institution or across the sector. There will be clear value and benefit to others. | ■ Many projects begin with an initial impact in mind. Mechanisms should be embedded to encourage project lead(s) to reflect upon the ongoing impacts of their project at key points in its lifecycle. For example, the impact upon stakeholders (students, departmental colleagues, institutional staff) and policy and practice (departmental, faculty, institutionally).<br>■ Has the scale, and/or scope of the project been extended from original plans?<br>■ How is the project contributing to the national policy debate?<br>■ Have there been stakeholders, beyond those originally envisaged, engaged in the project? Are there 'user stories' or evidence from learners? |
| 7. Evaluation | Evaluation is an important part of the educational development process. A robust commitment to (internally) evaluate should be in place prior to the commencement of any project. | ■ While all proposals should demonstrate a commitment and plan for evaluation at their outset, evidence is needed that this is embedded throughout a project and not only at its beginning and end. An evaluation plan should be maintained and updated.<br>■ Systematic evidence of not only the capture of data throughout, but also changes to the project or activity in response to emerging findings should be sought throughout the project lifecycle. Evaluation should include the views of key stakeholders at all stages.<br>■ Is there (new) engagement of project lead(s) with institutional and national activities relating to evaluation and educational research or specific learning and teaching events and activities? |

Table 1: Sustainability indicators for learning and teaching enhancement. (continued)

| Sustainability Indicator | Description | How might this be interrogated/evidenced? |
|---|---|---|
| 8. Dissemination | Dissemination indicates there is a substantive story and an individual belief in the ideas being shared. It demonstrates a clear personal commitment to the activities and ideas. | ■ Evidence of (ongoing) awareness raising and sharing information about the project and its activities within the host department and institution (including online).<br>■ National dissemination of findings and learning through, for example, conference talks and published works, or work with professional organisations.<br>■ Collaboration with others to encourage uptake of developed practices, for example through 'practice-transfer' schemes (see for example, Pugh & Grove, 2014). |
| 9. Developing a Community Identity | Bringing together like-minded individuals or those who wish to learn from each other, share ideas and practices, or oversee the ongoing nature of activities within a community, through a co-ordinating and networking function. | ■ Encouraging projects to include an initial literature review to explore the context of their proposed work relative to existing international practice.<br>■ Networking, through conferences and events, but also through activities and meetings established by the project lead(s) both within their institution and outside of it (including online).<br>■ The visibility of the individual within their community and institution. For example, invited talks, or contributions to learning and teaching consultations. |
| 10. Professional Development and Recognition | Professional development includes individual learning, learning amongst other engagers, or a concerted effort to transfer the knowledge and expertise to others through mentoring or training events. Recognition involves an independent acknowledgement of the contribution an individual has made through their work and activity. | ■ Collaborative activities with others to develop ideas and inform practices. For example through mentoring.<br>■ Participation in workshops, events and special interest groups related to the theme of the project.<br>■ In project reports, seeking evidence of how the skills and outlook of the project lead(s) have developed, through new experiences, and possibly evidenced through a reflective component in the project reports.<br>■ What is the expertise of the individual in relation to learning and teaching enhancement? Is there either a track-record or a clear personal rationale for the activity?<br>■ Reward and recognition received by the individual as related to their work. For example: professional fellowships, institutional and national teaching awards, and promotion. |

# A11. The oversight of mathematics, statistics and numeracy support provision at university level - A guide for Pro-Vice-Chancellors

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mathematics and statistics support

# The oversight of mathematics, statistics and numeracy support provision at university level

## A guide for Pro-Vice-Chancellors

by Tony Croft, Michael Grove & Duncan Lawson
for the **sigma** Network

HIGHER EDUCATION FUNDING COUNCIL FOR ENGLAND hefce

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# Preface

The seminal report, *Measuring the Mathematics Problem* (Hawkes & Savage, 2000), recommended that: *"prompt and effective support should be available to [higher education] students whose mathematical background is found wanting."*

Over the last 20 years, mathematics support has developed significantly as a response to this recommendation and now forms a respected part of the provision in many higher education institutions: *"Mathematics and statistics support is an essential part of any university. It is critical to a wide range of social sciences as well as professions such as nursing, an obvious benefit across all the STEM subjects and a boon to mathematics…Mathematics and statistics support has now attained a critical mass and overcome the significant hurdle where universities worry whether offering such support is an indication of modest aspirations. The accepted position is now that it is a student's right to receive support with the mathematical content of their degree. The question for all HEIs should now be 'How can universities provide a full range of qualifications and advance the widening participation agenda without maths support?'"* (David Youdan, Executive Director of the Institute of Mathematics and Its Applications quoted in Fletcher, 2013).

For more than a decade, **sigma** has produced numerous publications to support the work of practitioners and researchers within the mathematics support community. This guide is written for Pro-Vice-Chancellors who have responsibility for overseeing the quality of learning and teaching and the student experience.

Throughout this guide, the phrase 'mathematics support' will be used as a short-hand for the more correct (but longer) 'mathematics and statistics support'. Further, the term includes more basic numeracy support, particularly where this is relevant to students' ability to gain access to graduate level employment.

We hope that you find the distilled wisdom within this guide to be of value as you oversee, champion, develop and strive for excellence in student support within your own institution.

**Tony Croft, Michael Grove & Duncan Lawson**
August 2016

# Chapter 1.
# Why offer mathematics support?

- Significant numbers of students are entering higher education lacking the mathematical skills they require to deal competently with the mathematical content of their courses: *"We estimate that, of those entering higher education in any year, some 330,000 would benefit from recent experience of studying some mathematics (including statistics) at a level beyond GCSE. At the moment fewer than 125,000 have done so."* (ACME, 2011).
- This affects a very broad range of disciplines including, increasingly, the biological and social sciences: *"The UK is weak in quantitative skills, in particular but not exclusively in the social sciences and humanities... another reason for the poor skills of undergraduates is the dearth of academic staff able to teach quantitative methods."* (British Academy, 2012).
- This *'mathematics problem'* (LMS, IMA & RSS, 1995, Hawkes & Savage, 2000) remains a major issue despite being extensively researched, being the basis of several inquiries and being reported on for many years (Croft et al., 2015).
- It is widely accepted that universities have a responsibility to try to deal with the mathematical needs of their incoming students: *"Higher education has little option but to accommodate to the students emerging from the current GCE process"* (Smith, 2004) *and "One reason why students leave higher education without completing their qualification, or fail, is that they are not well prepared in key skills before they start. Higher education institutions therefore have to identify knowledge and skills gaps and provide support to students, for example remedial or catch up courses in mathematics in the first year."* (NAO, 2007).
- There is evidence that many academic staff lack the skills to deal with the increasing quantisation of their disciplines: *"English universities are side-lining quantitative and mathematical content because students and staff lack the requisite confidence and ability."* (RSA, 2012).
- Mathematics support has grown substantially in the past 20 years as an effective and popular vehicle through which many students can address mathematical shortcomings and improve their confidence (Perkin, Croft & Lawson 2013).
- Even students with the highest grades on entry to mathematically intensive courses encounter difficulties with their studies: *"…undergraduate students in the Russell Group universities also experience problems with mathematics and statistics, despite the fact that in the main such 'high tariff providers' are capable of recruiting students with very good academic qualifications…"* (Tolley & Mackenzie, 2015).
- Issues are not only restricted to undergraduate level: *"Postgraduate courses, which are often more quantitative than their undergraduate counterparts, give rise to further challenges."* (Tolley & Mackenzie, 2015).
- For many students, employer numeracy tests are an increasingly important part of the employment process: *"…after leaving university many graduates will find themselves faced with numerical reasoning tests when competing for jobs. Yet only 16 per cent of undergraduates studying subjects other than maths have an A-level in maths under their belt. Often they will have forgotten much of what they once knew, and even if they haven't, their confidence in their own abilities may be low."* (Willetts, 2013).
- Far too many students are entering higher education with a negative perception of mathematics: *"My GCSE maths experience has put me off it for life."* (Brown, Brown & Bibby, 2008).



# Chapter 2.
# What is mathematics support?

- The term *mathematics support* should be interpreted to mean a facility offered to students which is **in addition** to their regular programme of teaching. The term should be regarded as an umbrella term encompassing a wide range of provision.
- The most common provision is the mathematics support centre which typically offers one-to-one support to students on a drop-in basis (Lawson, 2012). Other models of support are used effectively by universities (Marr & Grove, 2010).
- The key feature of a successful mathematics support centre is having a tutor with whom students can discuss their mathematical issues and problems on a one-to-one basis. In addition to addressing technical knowledge, it is important for the tutor to address the student's confidence.
- A mathematics support centre provides a safe learning environment where students can access a range of resources and interact with other students as well as drawing on input from a tutor when needed.
- Research evidence demonstrates that students value the change in power dynamic in a maths support centre as opposed to a member of staff's office. *"When they [staff] are in maths support, you know they're there to help people and you're not bothering them. If you go to their office, you've got your stuff in your bag, there's nowhere to get it out to show them, you know there's a queue of people behind you, they were doing something before you arrived if there wasn't anyone in the queue ahead of you, so you feel like you're bothering them, it's their space as well and you're going into their office, whereas maths support is neutral ground for everybody … it doesn't belong to anybody, you've got your stuff out and they will work their way round the table to come to you, you have your work out ready even if you've put it to one side, so you can flip back to it and say 'can you just help me with this'"* (Solomon, Croft & Lawson, 2010).
- Tutors in mathematics support centres can offer alternative explanations to aid student learning.
- Mathematics support centres complement other initiatives aimed at addressing the *'mathematics problem'* such as bridging courses, summer schools, online resources, diagnostic testing and curriculum re-development.
- The key purpose of mathematics support centres is to assist students to achieve their full potential. For some, this will mean gaining the few extra marks needed to turn a good result into an excellent one. For others, it may be that a fail becomes a pass.
- The exact form of support offered may vary from institution to institution, but the ends are the same: to build students' confidence in mathematics and thereby to enable them to be more successful in the study of their primary discipline.
- Mathematics support centres often assist students in the preparation for employer numeracy testing.

# Chapter 3.
# Establishing mathematics support provision: delivery and evaluation

## Delivery of mathematics support

- Mathematics support can encompass a variety of forms: from small-scale, departmental and subject based initiatives, to multi-site drop-in centres accessible to learners from a range of programmes (Lawson, 2012; Marr & Grove, 2010).
- A mathematics support centre can be based in a range of locations across a university campus. In some institutions the mathematics support centre is based within the library or central study skills unit; in others, the centre can be departmentally based or even peripatetic.
- Crucial to mathematics support is the role of the tutor. Working in a mathematics support centre is challenging, and as such, tutors need to have a particular set of skills that means not everyone is suitable.
- It is essential tutors are selected for their ability to work within a mathematics support centre environment. Essential skills include: ability to recognise students' individual needs; comfortable working on a one-to-one basis; patient; able to explain mathematical ideas in multiple ways; excellent interpersonal skills; able to work (and communicate) with students of a range of abilities and from different disciplinary areas.
- Across the country, mathematics support centres use a range of staff as tutors including academic staff, hourly paid staff (often former teachers) and postgraduate students.
- All tutors need to receive training before commencing work in a mathematics support centre as this is quite different to in-course teaching, tutoring or demonstrating (Croft & Grove, 2011). This should be complemented by ongoing mentoring.
- Those working in mathematics support should be afforded the same development and recognition opportunities as those undertaking more traditional forms of teaching. In recent years, several staff involved in the delivery of mathematics support have been awarded National Teaching Fellowships.
- Since statistics support is often related to extended pieces of project work, it requires the tutor to gain an appreciation of the project as whole. As such, statistics support requires statistics specialists and frequently uses bookable appointments as opposed to drop-in.
- A successful mathematics support centre requires day-to-day oversight and management to ensure the quality and continuity of provision.
- Additionally, buy-in from a senior management 'champion' is needed; someone who not only secures financial support for the provision, but also brokers linkages, raises awareness, and enables departmental and central service buy-in.
- Many universities are identifying their funding of mathematics support in their Office For Fair Access (OFFA) agreements, citing the key role of such support in promoting widening access, particularly at the transition to university.
- A large number of freely accessible mathematics and statistics support resources are available for institutions to use in a range of ways with their students and there is much good practice upon which to build and develop provision. The **sigma** Network continues to develop this resource base.

## Evaluation of mathematics support

- Evaluation is necessary to ensure the continued enhancement of mathematics support provision.
- There may be three key foci for the evaluation of a mathematics support centre: Measuring **usage** of facilities, resources and services; gathering **feedback** from students on their perceptions of the quality of the service; and, measuring **effectiveness** in terms of improvements in performance of students who use the service.
- Gathering data and feedback from students who use the mathematics support centre is relatively straightforward to determine usage patterns and quality of service (Green, 2012).
- Evaluation of the *effectiveness* of a mathematics support centre as a retention mechanism is challenging due to the many independent factors which impact upon a student's ability to succeed (Matthews et al., 2013).
- Evidence shows that a persistent minority of students who would benefit from mathematics support fail to access and take advantage of it despite multi-faceted strategies to encourage them to do so (Symonds, Lawson & Robinson, 2008). As such, careful consideration needs to be given as to how to promote mathematics support to all potential student users.

# Chapter 4. Institutional coherence: maximising the benefits

## Institutional coherence

- Significant external or 'top-down' factors have been responsible for changes affecting the whole HE system in England. These systemic changes include the move away from an elite to a mass system of tertiary education, widening participation, 'marketisation' through the introduction of student tuition fees, the emphasis given to the quality of the students' experience, the importance attached to their recruitment, retention, achievement and employability, and the publication of league tables.
- The importance of mathematics support not only in improving retention rates but also in attracting students, addressing issues of inequality and diversity and improving employability is now being recognised. Mathematics support is thus increasingly seen as one element of a wider brief to enhance the student academic experience.
- Prompted largely by the above cited external factors, university senior management is increasingly exercising oversight of mathematics and statistics support.
- Mathematics support should be regarded as enhancement provision for all students rather than remedial work for weak students, and so should be of interest to those responsible for enhancing quality in the institution including programme leaders, Heads of Department, Deans, PVCs (Learning and Teaching), Learning Development Managers, Careers advisors and many others.
- In 2014, a joint report to the Department for Business, Innovation and Skills (BIS) from OFFA and HEFCE (BIS, 2014) set out a shared national strategy for combining fair access to HE with student success. It advanced the view that the adoption of a broader, coherent whole lifecycle approach would benefit all students attending the full spectrum of HE providers across the whole sector. Mathematics and statistics support clearly has a vital role in this whole lifecycle approach.
- In most institutions mathematics support is one of a range of academic support services provided. Senior management oversight of all these services can enhance their effectiveness and coherence.

## Feedback into the curriculum

- There is great potential for mathematics support provision to make a broader contribution to an institution than simply its work with students. Many structural issues come to light in mathematics support centres (such as significant numbers of students having the same gap in expected knowledge, or mismatches between what is taught in the first two years and the demands of the final year of a degree programme). Consideration should be given as to how this information can be best fed back into curriculum development.
- The effectiveness of mathematics support can be enhanced by close co-operation between mathematics support tutors and academic staff teaching mathematically rich modules.
- In order to achieve this broader impact, it is necessary for mathematics support and those who deliver it to be seen as a key part of the academic provision of the institution. Appropriate and effective channels of communication should be in place to facilitate exchange of information across the institution.
- Consideration should be given as to how the experience of mathematics support can feed into delivery, training and support for those in mainstream teaching.



# Chapter 5. Mathematics Support and the Teaching Excellence Framework

- At the time of writing, the Teaching Excellence Framework (TEF) is still developing; however several elements of the Framework have been established. The impact of the TEF on the higher education sector is, at this point in time, unknown. However, if the impact of the Research Excellence Framework (REF) is a guide, it is likely to have a major effect over the coming years.
- One of the elements of the TEF that has been determined is that higher education providers (HEPs) who choose to submit to the TEF will be assessed against three main aspects:
    - Teaching Quality
    - Learning Environment
    - Student Outcomes and Learning Gain.
- A common set of metrics will be used to measure HEP performance in these aspects and HEPs will also submit a 15 page evidence-based contextual statement describing their approach to teaching and student outcomes.
- A strong mathematics support provision will be powerful evidence of the importance a provider attributes to a supportive learning environment. The investment of funding to assist students to achieve their full potential is a clear sign of a provider's commitment to teaching in the broad sense being used in the TEF.
- If the mathematics support provision is being properly evaluated (see Chapter 3), there should be both quantitative and qualitative evidence available to demonstrate how this element of the Learning Environment is providing effective support to students.
- Additionally, one of the metrics that will be used to measure the Learning Environment aspect is the Academic Support set of questions from the National Student Survey (NSS) (questions 10 to 12). Provision of high quality mathematics support in addition to students' regular teaching is likely to increase the student satisfaction in the areas covered by these questions.
- The other metric in the Learning Environment aspect is the HESA Retention data. There is research evidence of the effectiveness of mathematics support in increasing retention rates; a major whole national study in Ireland reported that *"22% of respondents who had availed of MLS [mathematics learning support] had considered dropping out of their course due to mathematical difficulties and almost two thirds of these students stated that availing of MLS had a positive impact on their retention on their course."* (O'Sullivan et al., 2014).
- At present there are no robust measures of learning gain. For the first few years of TEF, at least, the focus in the aspect Student Outcomes and Learning Gain will be on employment data and, in particular, the percentage of graduates in employment or further study (as measured by the Destinations of Leavers from Higher Education (DLHE) survey). As has been illustrated in Chapters 1 and 2, mathematics support has an important key role to play in this area.
- An increasing number of graduate employers are using numerical reasoning tests as part of their selection processes. Many graduates have not explicitly studied mathematics since their GCSEs (at least 5 years previously). The role of mathematics support in preparing them for these tests is vital in helping them to secure employment.
- It has also been made clear that the TEF will use 'splitting' to compare the performance of students with different characteristics (for example, those from lower POLAR (Participation Of Local AReas) quintiles compared with those from higher POLAR quintiles or those with disabilities compared to those with no disability). The role that mathematics support plays in addressing issues relating to student confidence, notably through the one-to-one support and the tutor-student relationships that are developed, can be particularly relevant to many of these students and so help to reduce any 'performance gap'.
- TEF Year 3 (2017/18) will pilot assessment at discipline level with a view to complete discipline level assessment in TEF Year 4 (2018/19). In many disciplines which have a growing dependence upon mathematical and quantitative skills, the absence of mathematics support is likely to be viewed as a serious deficiency.

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# About the authors

**Tony Croft** is Professor of Mathematics Education at Loughborough University and has developed mathematics support there for many years. He is a Director of the **sigma** mathematics support network and a Director of **math**centre – the UK's virtual mathematics learning support centre. He was awarded a National Teaching Fellowship in 2008. He is a Fellow of the Institute of Mathematics and its Applications and a Fellow of the Higher Education Academy.

**Michael Grove** is a Reader within the School of Mathematics at the University of Birmingham where he works on issues relating to learning and teaching within higher education and teaches mathematics to undergraduate students. He is a National Teaching Fellow (2014), a member of the Directorate of the **sigma** mathematics support network, and is responsible for the University of Birmingham's Mathematics Support Centre. He is also a visiting Associate Professor at the University of Leeds and a Fellow of the Institute of Mathematics and its Applications.

**Duncan Lawson** is currently Pro-Vice-Chancellor (Formative Education) at Newman University, having previously been the founding Director of **sigma** at Coventry University where he worked in mathematics support for over 20 years. He is a Director of the **sigma** mathematics support network and a Director of **math**centre – the UK's virtual mathematics learning support centre. He is joint editor of the journal *Teaching Mathematics and Its Applications:* An international journal of the IMA. He was awarded a National Teaching Fellowship in 2005.

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sigma
network for excellence in
mathematics and statistics support

**sigma** – Network for Excellence in Mathematics & Statistics Support
Mathematics Education Centre
Loughborough University Leicestershire LE11 3TU United Kingdom
T +44 (0)1509 227460

Loughborough University

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# A12. Mathematics and statistics support centres: Resources for training postgraduates and others who work in them

Croft, A. C. & **Grove, M. J.** (2016). Mathematics and statistics support centres: Resources for training postgraduates and others who work in them. *MSOR Connections,* 14(3), pp. 3–13.

CASE STUDY

# Mathematics and Statistics Support Centres: Resources for training postgraduates and others who work in them

Tony Croft, Mathematics Education Centre, Loughborough University, Loughborough, UK. Email: A.C.Croft@lboro.ac.uk
Michael Grove, School of Mathematics, University of Birmingham, Birmingham, UK. Email: M.J.Grove@bham.ac.uk

## Abstract

This article provides a rationale for the focused training of postgraduates (and others) who work in mathematics and statistics support centres. It outlines a format for training that has been found to work well through workshop-style events run at universities around the country over the last five years. Within any form of training there are important topics for discussion and a wealth of resources freely available for those centre managers who wish to develop training for their own tutors. Tutors are in the front line of tackling the lack of confidence and skill deficits of students who arrive at support centres looking for help; tutors who are well-briefed in terms of the challenges they are likely to face and how they can best respond to students who are finding university mathematics and statistics particularly difficult will help to ensure that the services offered genuinely contribute to enhancing the student experience. While training for new mathematics support tutors is important, of equal, if not greater importance is identifying tutors with the right skills and abilities to work in mathematics and statistics support. We conclude by considering the recruitment of postgraduate tutors and by undertaking a brief discussion about the value of training to the tutors themselves including contribution to professional recognition that is gaining increased importance. Further sources of information can be found within Croft and Grove (2011) which forms a training resource pack, Croft, et al. (2013) and in the resources section of the **sigma** network website (2016) which includes PowerPoint slides and training activities that can be used in, or adapted for, workshops.

**Keywords:** Mathematics support, tutor training, support centre, postgraduate tutors.

## 1. The rationale for providing training

In 2013, Perkin, Lawson and Croft found that 88 out of the 103 institutions responding to their survey offered some form of additional learning support to students, often through Mathematics and Statistics Support Centres. These centres offer facilities and services to students to help them build confidence, address skills gaps and offer opportunities that complement students' traditional diet of lectures, tutorials, problems classes and personal tutorial sessions. This supplementary support is designed to be supportive, non-threatening and non-judgemental. It is a realistic response to the well-documented (see, for example, Croft, et al. (2015) for a summary) day-to-day reality in most universities of significant numbers of students who find themselves ill-prepared for the mathematical demands of their courses.

Many mathematics support centres make extensive use of postgraduate students working as tutors. Providing mathematics support is not the same as the routine tutorial support that many postgraduates undertake as part of their own programmes of study and for which training, typically at an institutional level, may have already been provided. Amongst the reasons for this difference are:

- Tutors are unlikely to know in advance who the students are, the departments they have come from, or the level they are studying at.
- Tutors are unlikely to know what, or indeed how, the students should have been taught and what they should have already learned.
- Students may be from departments that are not traditionally taught mathematics modules (for example geography and business studies) and may be alienated, intimidated and nervous.
- Some students are likely to present with statistical as opposed to mathematical problems and tutors need to be aware that offering statistics support differs, as we shall discuss below, in important ways from offering mathematics support.
- The students may be poorly prepared for what is expected of them due to mismatches between the mathematical or statistical demands of their courses and entry requirements.
- Some students may have additional needs that may or may not have been declared.
- A student's perception of the mathematics support service may be based on a single interaction with the tutor, as opposed to that which can be developed over time through weekly tutorial sessions.

When postgraduate students offer routine tutorials for specific modules:

- They will have contact with the lecturer who has taught the module and can discuss their expectations and requirements of them.
- They will usually have advanced sight of problem sheets, for which solutions are likely to have been provided, and can prepare accordingly. Further they have access to lecture notes, and indeed the lecturer, should queries arise.
- The expectations on tutors are tightly constrained by the module, i.e. they will be aware of pre-requisite modules and may well be based in the same department as the students they tutor.
- Students and tutors can get to know each other in a tutorial group situation and develop a rapport. Building such a relationship is not as straightforward in a support centre environment when students might meet different tutors at different times.

With these differences in mind, support centre tutors will benefit from a training session that explores:

- The rationale for mathematics support and how it is implemented including awareness of the various models in use throughout UK universities.
- The ethos of their own centre and the importance of being excellent ambassadors for the service.
- The types of students who might use the centre, the courses they are studying and the level they are working at.
- An awareness of students' different learning styles and specific learning differences.
- Strategies to adopt when problem solving in the support centre and, in particular, what to do in the event of being unable to solve a student's mathematical problem.
- The broad range of issues that might arise including welfare, plagiarism, students seeking help with coursework assignments, and ethical issues.
- To whom they should turn for help and advice.
- The extensive range of existing resources and materials that are available to help them in their role.
- How they might use their experience towards professional and career recognition.

## 2. A model for postgraduate tutor training

The **sigma** Network is a HEFCE-funded collaborative venture to build a community of practice for those working in mathematics and statistics support. Anyone working in the field is encouraged to get in touch and contribute to its activities with the website (**sigma**, 2016). Through **sigma** a comprehensive range of freely available resources have been developed for centre managers (and others) to use as the basis for local training of postgraduates using a workshop format. Furthermore, a Guide (Croft and Grove, 2011) has been written specifically for postgraduates who tutor in mathematics support centres and is available for free download. The format of this Guide mirrors the structure of the workshops that have been run successfully in the years since 2010 and has involved adapting a format first introduced very successfully by the Maths, Stats & OR Network in 2005 (Grove, Kyle and Cox, 2006) that was applied to postgraduate students who demonstrate mathematics. The format of a typical day-long workshop is shown in Figure 1.

| | |
|---|---|
| 10:30-:10:45 | Welcome and introductions |
| 10:45-11:30 | Mathematics support – what is it? |
| 11:30-12:30 | Problem solving |
| 12:30-13:00 | Principles of maths support – do's and don'ts |
| 13:00-13:30 | Lunch break and networking |
| 13:30-14:00 | Offering statistics support |
| 14:00-14:30 | Tutoring in the mathematics drop-in centre – awareness of individual differences and needs |
| 14:30-15:30 | Group activity – exploring various scenarios |
| 15:30-16:00 | Resources and networking with others |
| 16:00-16:30 | Question and answer session |

**Figure 1: Timings and structure for a typical postgraduate tutoring workshop**

Experience suggests that, ideally, the workshop should be delivered by at least two members of staff with experience of delivering mathematics support. Where possible, additional staff with specific expertise (for example a statistician or an additional needs tutor) can be engaged to run, or assist with, specific elements. It is also valuable to invite delegates from several different institutions so that they all learn from the experiences of their peers working in different environments and with different models of mathematics support. Experience also suggests that a total group size of 20-30 is optimal; with too few tutors present the interactions and discussions will be hindered. Grouping delegates in sets of four or five has also been found to work well, particularly when asked to discuss the questions or scenarios posed.


**Figure 2: A typical postgraduate tutoring workshop in progress**

Here we discuss briefly the key features of each of the sessions of Figure 1. This provides information based upon our experiences of delivering such sessions, but is naturally complemented by the additional detail that can be found within the Guide of Croft and Grove (2011).

### 2.1. Welcome and introductions

During this brief session delegates are asked to spend a few minutes considering what they want to learn/gain from the day, and at least one question they hope will be answered. They are invited to write these down on Post-it notes that they either retain for later reference or share with others straightaway on a communal board. Examples of questions noted at previous events include:

- *How can we backtrack, and un-confuse a student when a first attempt at an explanation is too complex?*
- *What do I do if I think a student has been told the wrong technique or something is just plain wrong in their notes?*
- *How do we advise students about presenting their answers well?*
- *What if I myself am not sure of the problem or I make mistakes?*
- *How do I divide up my time between all the students who need help?*
- *What is the best approach to helping the "here's my page of algebraic manipulation – where have I gone wrong?" type question – when pressed for time this is the hardest type of question!*
- *How do we approach helping with coursework?*

Here the purpose is not to answer these questions, but to use this session as a means of generating interaction with the tutors that is critical for the success of the day. It is also particularly helpful for identifying any common issues that may be related to, for example, the specific model of support provided by a particular institution.

## 2.2. Mathematics support – what is it?

Again, to stimulate the necessary interaction with both the workshop leads and between tutors, the following questions have been posed for delegates to discuss in their small groups:

1. *What do you think mathematics support is and why might it be necessary now?*
2. *What is a 'mathematics (and/or statistics) support centre'?*
3. *What do you know about the nature of mathematics support in your institution? Who can access it? Where is the support offered and when? Are academic staff available for consultation where necessary?*
4. *What do you think is the role of you as a tutor in your mathematics support centre?*

The remainder of this session takes the form of interaction between the small groups and the workshop leads to share thoughts and ideas and build discussion. To aid the structure, a PowerPoint presentation is used to share the thoughts of the workshop leads in response to the above questions, however, this again is a basis for stimulating discussion and idea development rather than didactic presentation.

Mathematics support refers to activities and resources provided to support and enhance students' learning of mathematics and statistics, in any discipline, at any level of higher education and which are provided in addition to traditional lectures, tutorials, examples classes, and personal tutorial sessions. Whether this definition is appropriate for the delegates when they are considering their own institution, and in particular whether the local support is available to students in any discipline and at any level, is usually a good starting point for discussion. We have met tutors who only work to support students in a management or business school for example, and others who work in centres where the support is only available to engineers. Experience can be very varied and it is useful for all present to hear about the range of models in use. Tutors usually recognise that this support is informal, not credit-bearing, voluntarily accessed, and should be supportive and non-threatening. Others have suggested that it provides alternative approaches to problem solving and helps develop independent learning (through the discussion of strategies and techniques for problem solving as well as the range of resources available for independent study), and that this is a skill those working in support centres should aim to instil in students.

Discussion about why support is perhaps required more now than ever before enables the workshop leads to present information about:

- *"The mathematics problem*" in terms of insufficient numbers of students studying mathematics post-16 in the UK and the lack of preparedness for the demands of mathematics at university (Hodgen, et al., 2010; Hawkes & Savage, 2000),
- The increasing quantification of disciplines such as the biosciences and the social sciences (ABPI,2008; British Academy, 2012).
- Widening access to higher education to increase participation amongst under-represented groups.
- Students arriving for higher education with increasingly diverse mathematical backgrounds.
- With the marketisation of higher education come demands from students themselves for a high quality learning experience and appropriate academic support.
- Recognition within institutions of the importance of 'student satisfaction' and the National Student Survey.

## 2.3. Problem Solving

In this session, delegates consider a variety of mathematical problems in their small groups. The aim is not necessarily to solve any of the problems but to discuss problem-solving strategies and how they would support a student arriving in their support centre with such problems. By providing problems that the delegates will be unfamiliar with also enables debate and discussion about how to deal with scenarios within a support centre where they do not know immediately how to tackle a student's problem.

Subsequent discussion naturally leads to:

- An appreciation that it is not the role of tutors to 'tell the student the answer' and ideally the student should come to their own conclusion(s) with scaffolding provided through the tutor's questioning.
- An understanding that the tutors do not always need to know the answer, but at the same time ensure that the student leaves the centre having made some progress.

A selection of problems that have been used in workshops can be found in the guide (Croft and Grove, 2011) and in the **sigma** resource pack on the **sigma** Network website (2016). Further examples, and indeed an excellent discussion on what constitutes genuine problem solving, can be found within Hawkes (2015).

## *2.4. Principles of maths support – do's and don'ts*

In this session the delegates, within their groups, are asked to think about what they might do (and what they should not do):

1. Prior to working in the centre.
2. During a drop-in session.
3. Afterwards.

Discussion about what tutors might do prior to working in the centre usually includes the following points: getting to know who is responsible for running the centre and who the tutor should contact if they have any concerns; understanding the purpose of their centre and which students can use it; the resources available both in the centre and through associated websites such as **math**centre (2010). It is important that tutors know they can establish boundaries concerning what they have sufficient knowledge to tutor and what they don't (for example statistics, mechanics, research methods, etc.), and this forms a good opportunity for tutors to consider how they can make the most of the skills and expertise their colleagues possess. Finally, there is a need to ensure tutors are aware of emergency evacuation procedures and have information about who to call in case of emergency (for example local first aiders).

When discussing do's and don'ts whilst working in a drop-in session, the following issues usually arise:

- the importance of welcoming students to the centre and introducing yourself as the tutor;
- asking about the course and level the student is studying before commencing the mathematics or statistics - knowledge of the students' course can be very important in determining the approach taken to tutoring the student;
- the importance of sharing your time equitably with all those waiting for help;
- not being embarrassed about letting the student know you don't necessarily understand how to solve a problem – but instead working together to try to understand by asking questions and referring to lecture notes and other resources;
- the importance of showing the student respect and not demeaning them, even inadvertently – remember the student may have needed a great deal of courage to enter the centre at all and the way they feel treated will determine whether they persevere or not; encouraging the student to return, perhaps suggesting some additional work they should do in the meantime.

### *2.5. Offering statistics support*

It is generally recognised that offering statistics support is very different from offering mathematics support. There are a number of reasons for this:

- Students may arrive seeking help with introductory exercises to calculate, for example, measures of central tendency or spread. They may be attempting routine exercises, for example using the normal, binomial or Poisson probability distributions. Tutoring these students in a support centre is akin to tutoring mathematical topics.
- However, students might equally arrive seeking help with a particular statistical software package that they are using to analyse data (SPSS, R and others). It is quite possible that the tutor will not have used these packages. The **stats**tutor website (2010), mentioned in the section below, has a wealth resources that can help with these aspects and to which students can be referred.
- Some students may be seeking more complex advice and guidance on how to design and analyse a survey or an experiment. Often this is part of a final year project. Some students may seek to analyse data for a PhD thesis. In these cases assisting the student may demand more time than usual and a broader range of skills to help them.
- The interpretation of the output from statistical calculations is usually critical and might well require detailed knowledge of the context of the problem – knowledge that the tutor may not have.
- It is crucial that the tutor is aware of the level and discipline area of the student – sometimes a simple 'this is how you do it' might well be an appropriate response. For others, especially postgraduate students, it might be appropriate to recommend that the student spends time understanding the statistical requirements of the problem they are tackling and to develop the requisite knowledge for themselves.

For these reasons, and in an ideal situation, the statistics support tutor should be both a very experienced statistician and teacher. In a less than ideal situation, those responsible for running the centre need to be very clear about which students (courses and levels) can attend for help, and whether the tutors do indeed have the necessary skills and experience. The **stats**tutor website (2010) has training videos concerned with statistics tutoring do's and don'ts.

### *2.6. An awareness of students learning styles, differences and needs*

Crucial to the success of a support centre is the tutor's awareness that students present with a wide range of backgrounds, interests, and learning styles. Of course some are likely to have specific learning differences that have the potential to impact upon their learning. There is no expectation that tutors have specialist skills to deal with students presenting with neurodiversities such as dyslexia, Asperger's syndrome, or dyscalculia, but it is possible that they will come across students like this and should know that a level of sensitivity is required. Croft and Grove (2011) contains specific subsections that discuss each of:

- Thinking styles.
- Learning styles.
- Maths anxiety.
- Specific learning differences (SpLD).
- Counselling.

Tutors should be warned that under no circumstance should they attempt a diagnosis nor suggest to a student that they may have a SpLD. If in doubt, they should refer to the centre manager or an appropriate academic such as a personal or welfare tutor.

### 2.7. Scenarios that might arise

Groups are given several wide-ranging scenarios that have arisen in real support centres and asked to discuss how they would respond. Scenarios provided include ones such as:

- *A first year student turns up at the centre with a copy of a diagnostic test that they have been given during the first week of term, and their marked attempt. They scored 23%. What might you do?*
- *A mature, first-year, overseas student comes into the centre. They have difficulty in explaining what their problem is, but show you a problem sheet from a module being studied in the Business School. The sheet has several questions, each of which has a scenario leading to a linear programming problem. It is clear that the linear programming problem must first be formulated, and then solved using either the simplex method or a spreadsheet (Excel, or a more specialist package). They seem to have little idea where to start. What might you do?*
- *A student arrives and states: "I am doing a final year project and am very unsure of my statistics…My supervisor advised that I make an appointment with someone at the maths help centre and explain my project to them and then perhaps they would explain to me what tests I needed to use and why." What might you do?*

A number of other possible scenarios are available within the Guide (Croft & Grove, 2011) and also in the resources section of the **sigma** website (2013). Of course, there are no simple answers to any of these questions but tutors have found it valuable to hear how others would respond and the suggestions they make.

### 2.8. Resources

Over the last decade a wealth of resources for use in mathematics support centres, by both students and staff, has been created by the community and through various funded projects. A support centre should have access to these resources so that students can be directed and help themselves. The **math**centre website (2010) focuses particularly on material that is known to be problematic at the transition to university. The **math**tutor website (2010) contains much of the same material – videos, teach yourself booklets, diagnostic tests, etc. but arranged in a sensible order for self-study: arithmetic, algebra, functions and graphs, sequences and series, geometry, vectors, trigonometry, differentiation and integration. The **stats**tutor website (2010) contains a growing collection of statistical resources.

## 3. Delegate reflections on the training workshops

For each of the workshops that have been run, delegate feedback has been collected. This has not focused upon obtaining ranking scores, but obtaining specific comments that can be used to develop the events through a feedback loop. This has led to the workshop format, structure and content we describe here, and three key principles for delivering these: Practice sharing; an informal environment; and, interactivity.

A key feature of the feedback is that delegates welcome the opportunity to network and share ideas; something that is not always common even if tutors are based within the same institution. As such, this is something those running centres are encouraged to explore to aid the ongoing development of their tutors:

> *"Very easy to get external opinions on personal queries/dilemmas relating to the job. Also, set us thinking about aspects of our provision that we might not have thought about…"*
>
> [Delegate A]

> *"The brainstorming part of the event was important in terms of knowing each other's approach in dealing with different scenarios that may occur."*
>
> [Delegate B]

Another key feature is that to allow the sharing of ideas, an informal and relaxed environment needs to be established for the workshop sessions. Time and effort invested in this at the start of the workshop pays real dividends later and can help build confidence amongst the delegates:

> *"Very dynamic, interactive and easy going. Helped me get a bit more confidence as to my ability to be a good tutor."*
>
> [Delegate C]

But most importantly, it is essential that the sessions are very interactive and not consist solely of presentations by the workshop leads. The interactivity of the workshops is one of the most common comments cited in a section of the feedback form entitled 'what I liked most':

> *"…nice mixture of interactive sessions."*
>
> [Delegate D]

> *"Activities rather than presentations."*
>
> [Delegate E]

## 3. Recruiting postgraduate research students as mathematics and statistics support tutors

In a workshop held to discuss the training requirements of tutors (Croft, et al., 2013), discussion also took place regarding the *recruitment* of postgraduate research students, and in particular, how to find those with appropriate skills for working in a mathematics and statistics support environment. Advertisements for the post would better achieve their purpose if they were transparent and specified the target audience for mathematics support and their possible level of need. Recruitment was also often undertaken through recommendations from peers, lecturers, supervisors and staff, with an interview process of some kind. Tutor qualities or specifications could comprise of mathematics and statistics qualifications and teaching experience. Qualifications do not necessarily need to be discipline specific as a certain level of mathematics and statistics can be assumed from science based postgraduates. It is important however that learning and teaching skills are either present or that there is a potential for developing these skills with appropriate guidelines, nurturing and mentoring. Important skills are the ability to recognise students' needs, that is, to identify support needs beyond the need perceived by the student, helping students get to the actual need by unpicking the problem and by clever questioning.

Although teaching experience is desirable, tutoring in a support centre requires particular skills hence recruiting tutors with the potential for development as well as qualifications and experience is important. Working in a mathematics support centre is quite different to other forms of university teaching; not everyone possesses the necessary skills or abilities. Providing mathematics support is not about 'telling' the student the answer, but about encouraging them to identify their own mathematical problems, helping them tackle these for themselves with support and guidance, and providing suggestions and strategies for independent study. It requires individuals who are comfortable working on a one-to-one basis, who are patient, able to explain mathematical ideas in multiple ways, have excellent interpersonal skills, and are able to work with students of a range of abilities and from different disciplinary areas.

## 4. Recognition arising from mathematics support

Professional recognition for postgraduates for the time spent in training and the experience gained in a support centre is generally thought to be highly desirable. Not all postgraduate tutors will be interested but some, particularly those who have aspirations to work in university teaching might find formal recognition valuable. Certificates of attendance at training events can be produced easily, and in some institutions, training can contribute towards initial learning and teaching qualifications.

In one particular institution (Croft, et al., 2013) a scheme has been established to enable postgraduate research students with teaching responsibilities to achieve associate status recognition from the Higher Education Academy. The scheme allowed selected postgraduates to be supported, by being paired with a mentor, in their submission of an individual application on the basis of their experiences in teaching and learning in higher education.

In some institutions there are examples of tutors going on to secure teaching roles upon completion of their PhDs and working in a mathematics support centre can aid this. Tutors should be reminded of the fact that, for the reasons discussed earlier, they are undertaking one of the most challenging, but rewarding, forms of teaching in higher education. As such, they possess a wide range of skills, and should be encouraged to reflect upon these and cite their experience of working in mathematics support within their CVs and in any applications they might make. Former tutors who secure roles within their institutions can make an important contribution to mentoring and supporting new tutors as they commence their activities in a support centre.

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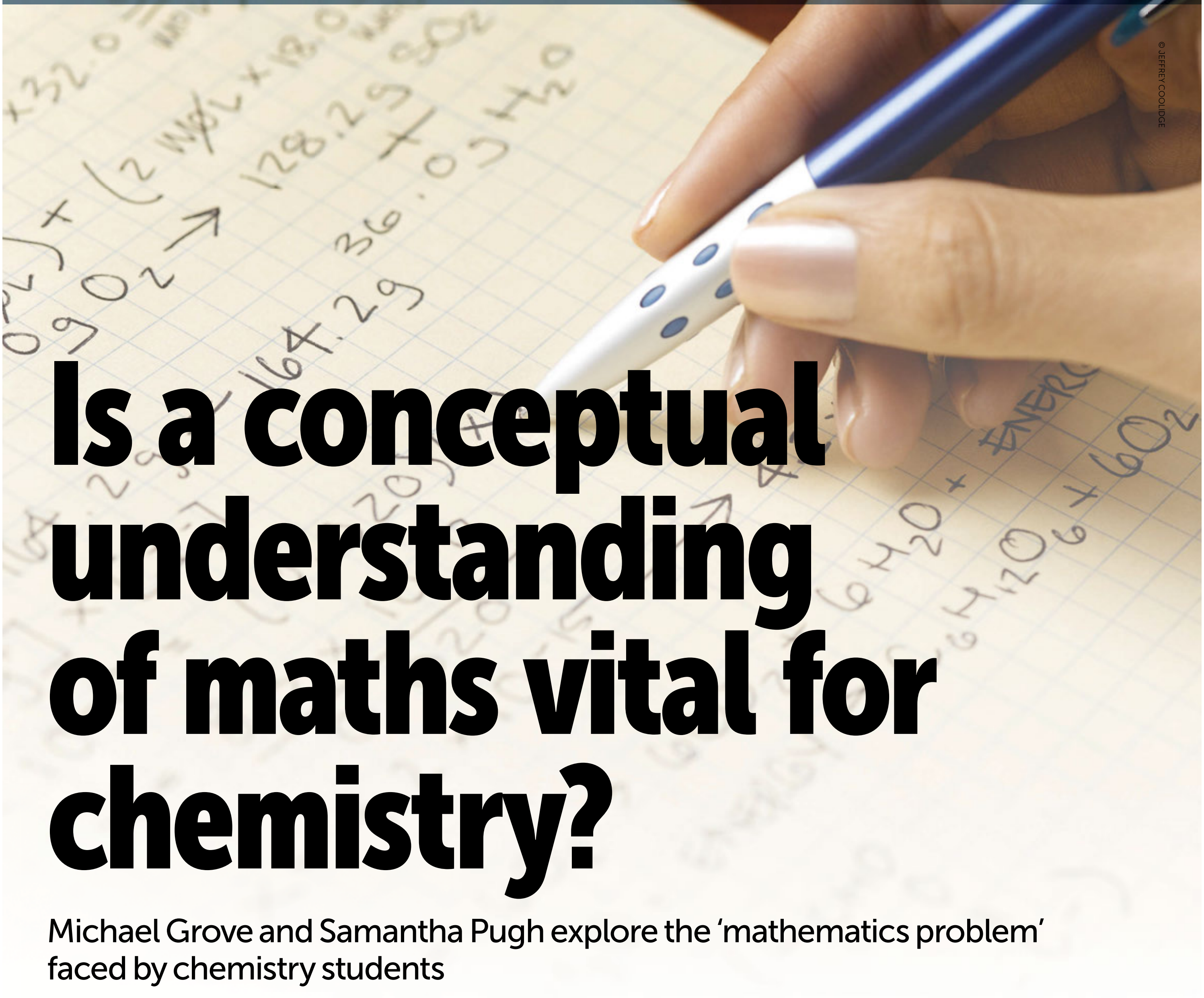
# A13. sigma – a network working

Croft, A. C., Lawson, D. A., Hawkes, T. O., **Grove, M. J.**, Bowers, D. & Petrie, M. (2015). sigma – a network working! *Mathematics Today*, 51, 36–40.

# A14. Is a conceptual understanding of maths vital for chemistry?

**Grove, M.J.** & Pugh, S.L. (2015). Is a conceptual understanding of maths vital for chemistry? *Education in Chemistry*, 52(1), pp. 26-29.



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# Is a conceptual understanding of maths vital for chemistry?

Michael Grove and Samantha Pugh explore the 'mathematics problem' faced by chemistry students

For those working within the disciplines of mathematics, physics and engineering in higher education, the 'mathematics problem' is all too familiar. The term describes the well-documented issues associated with the lack of mathematical preparedness of students as they begin their university studies.[1] While there has been considerable community-wide and institutional activity to tackle the problem,[2] for example the development of mathematics support centres and a range of online learning materials, there is evidence that the problem may now be different in nature, so a different solution is sought.[3]

While the root causes of the mathematics problem in mathematics, physics and engineering have been identified, in chemistry, the situation has never been entirely clear. In 2007, the then chief executive of the Royal Society of Chemistry Richard Pike attributed the issue to students not studying mathematics beyond GCSE level.[4] However, a year later, the Physical Sciences Subject Centre[5] review of the student learning experience in chemistry, indicated that that there was a mismatch between staff and student views of their preparation prior to starting a chemistry degree, even among the growing proportion who have studied A-level mathematics. Staff complained that students were ill-prepared in mathematics, but more than half the students surveyed said that the mathematics they did at school or college prepared them very well for their chemistry courses.

A serious attempt to understand the mathematics problem within chemistry has recently been undertaken by the Higher Education Academy.[6] Their staff and student survey report attributed the problem to a number of issues including lack of confidence, a gap between studying mathematics and entering the degree programme, more mathematics than expected in the degree programme and a lack of explanation of the relevance of mathematics to chemistry. Perhaps most striking was that despite citing difficulties, the majority of students reported that they had not accessed the additional mathematics support that was available.

## The research

In 2014, we established a programme of action research with the Universities of Birmingham and Leeds to investigate the specific nature of the mathematical issues affecting chemistry students and to identify what can be done from both a staff and student perspective to help

**Between students beginning a chemistry degree and the staff teaching them, there is a mismatch in views on how prepared the students are to tackle the maths in the course**


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alleviate these and identify areas where further research might be required.

Drawing on the expertise of a final-year mathematics and statistics graduate, we analysed historical data from two research-intensive chemistry departments. A third-year chemistry student researched the specific nature of the issues by conducting semi-structured interviews with academic staff. While there appears to be a tendency for chemistry departments to consider mathematics a 'physical chemistry issue', opinions were obtained from across organic and inorganic chemistry as well. Our findings indicated that the mathematics problem manifests across all areas of chemistry, particularly in relation to the skills required to support practical work.

## Findings

### *Prior mathematical experience*

Pre-university curriculum changes in 2000 reduced the number of students studying A-level mathematics to a record low, and with such a decline, the number of students with A-level mathematics choosing undergraduate chemistry was greatly diminished. Further, throughout this period, undergraduate science, technology, engineering and mathematics (STEM) numbers as a whole suffered a drastic decline and several high-profile university departmental closures were witnessed in chemistry. A crisis seems not to be too strong a word to describe the situation at the time.

In response, significant activity took place (between 2004 and 2012) to raise the profile of chemistry among young people. Interventions such as Chemistry: The Next Generation, and Chemistry for our Future led by the Royal Society of Chemistry and funded by the Higher Education Funding Council for England (HEFCE), were undertaken to address this decline. Data from HEFCE[7] show this was achieved with some success. Between 2002/03 and 2011/12, A-level chemistry entries increased by 39% and mathematics entries by 55%. At undergraduate level, full-time equivalent chemistry enrolments increased from 11,414 in 2001/02 to 16,050 in 2011/12.

In 2011, some 61% of chemistry A-level students (n = 40,132) also studied A-level mathematics,[8] and combinations of mathematics and chemistry accounted for the top four places (in total 16% of all combinations) in the most popular A-level combinations for Russell Group students (16%).[9] This would seem to imply there are a greater number of students with both chemistry and mathematics going on to study chemistry at undergraduate level, but does data from the university sector support this?

> **'the issue that exists is not a lack of fundamental knowledge and ability, but an inability to apply mathematics to solve unfamiliar and conceptual problems.'**

The review undertaken by the Physical Sciences Subject Centre[5] indicated that just over half the students responding (n = 328) had A-level mathematics, and in the recent Higher Education Academy Survey,[6] in which 721 students provided details of their prior mathematical qualifications, 75% indicated they had studied mathematics to A-level standard or equivalent, although no distinction is made between those with full A-level and those with AS-level qualifications. Further, as of recruitment commencing in 2014, 7 of the 24 Russell Group chemistry departments require mathematics as a compulsory subject, with 11 others asking for it as desirable.

Obtaining national data on chemistry undergraduates with A-level (or AS-level) qualifications is difficult, so two Russell Group chemistry departments (who did not require A-level mathematics) were considered as case studies. Results were mixed: one institution saw a steady increase in the number of students with A-level mathematics and the other remained broadly flat. Overall, 45% of chemistry graduates from one of the universities in the period 2009–2014 had some form of A-level mathematics qualification (pass or above), at the other the figure was 49% with a further 8% having AS-level, with at least two-thirds (within both) having A-level mathematics at grade B or above.

On the basis of this evidence, more chemistry students are studying more mathematics prior to university entry, and achieving the highest grades, yet the mathematics problem is reported as persisting. This would seem to dispel the idea that the mathematics problem in chemistry is down to many students having stopped formal lessons in mathematics two years earlier at the GCSE level[4] and there are other factors that we need to understand.

### *Understanding the importance of mathematics in chemistry*

Mathematics is an essential skill for chemistry students to master; the number of chemistry departments either requiring or recommending study of A-level mathematics is but one indicator. However, there exists a mismatch between staff and student understanding of its importance. For example, in the Higher Education Academy student survey,[6] over a quarter of respondents claimed that the relevance of mathematics to chemistry had not been explained to them. In addition, about one third of respondents had found more mathematics than expected in the degree programme.

We mapped the mathematical skills and knowledge needed within a typical three-year chemistry degree (*fig 1*). A range of mathematical skills are required throughout a degree, but typically, the teaching of mathematics is predominately concentrated in Year 1.[6]

Interviews with staff indicated that one issue compounding the mathematics problem in chemistry is that the importance of mathematics is not typically reinforced throughout an undergraduate degree. Students will be introduced to mathematical concepts in Year 1, but then may not apply some of these (usually the most conceptually challenging) until later years. Students don't have regular opportunities to apply their mathematical skills, and when they do, the emphasis is upon applications rather than understanding mathematical concepts. The situation is similar to those arriving with only GCSE mathematics; over time, students can lose fluency and understanding in the mathematical ideas and skills they developed in Year 1 as they are not continually, and explicitly, reinforced.

### *Is A-level mathematics the solution?*

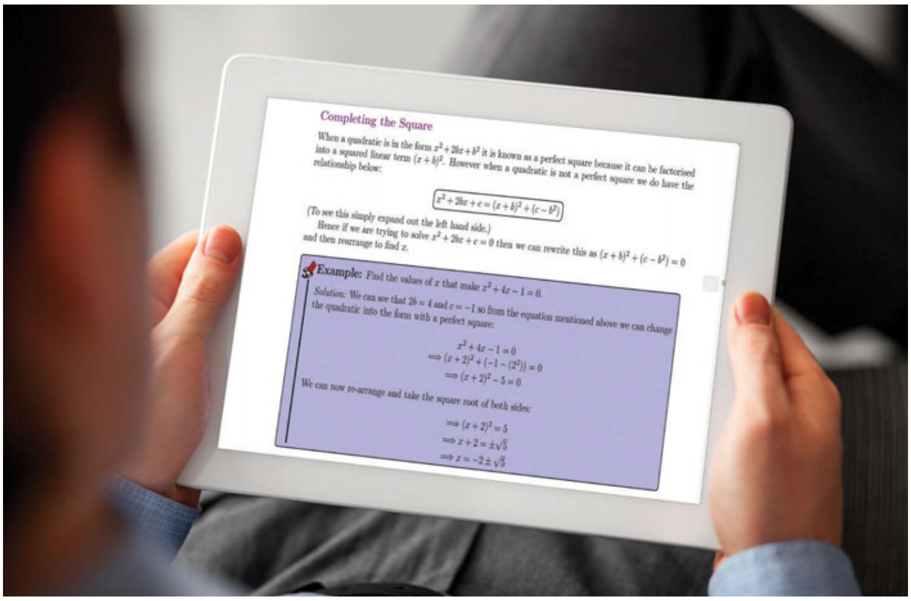
Within the two institutions we investigated, it was possible to compare how chemistry students with and without A-level mathematics performed during their first year. Students without A-level mathematics, or with lower than a grade B, must undertake a compulsory first-year module to introduce key mathematical concepts and techniques. A second compulsory module, focusing on the applications of mathematics in a chemistry context is taken by all students.

In one institution, the first module followed a common format, allowing questions to be categorised and analysed over five years.[10] Perhaps most strikingly, students struggled consistently with re-arranging and simplifying equations, yet performed better when such tasks were combined with questions involving logarithms. However, there is a much more fundamental underlying trend that is exemplified by differentiation and topics such as integration, differential equations and definite integrals. Students performed consistently well when required to differentiate functions, but less so when integrating functions or solving differential equations (which require mastery of techniques in integration). To an extent, differentiation can be regarded as procedural with a series of rules that can be followed (product, quotient, etc.); integration, however, requires far greater conceptual understanding. The variability of scores on these topics suggests a number of students struggle with this mastery.

**'What we are advocating is that the mathematics in chemistry should not be hidden and results merely presented. Instead, it should be embraced and explained…'**

With the second module, we analysed performance based on question types from the entire cohort. The findings highlight that (broadly) all students were able to solve process-orientated questions such as converting units and calculating concentrations, but all students, regardless of whether they had A-level mathematics or not, struggled with more conceptual problems requiring the application of mathematics, for example: 'Determine the minimum potential…'.

Academic staff commented that they felt that while students with A-level mathematics were generally more able and could perform well with formulaic or procedural mathematics questions, they struggled to take a conceptual chemistry problem, identify the necessary mathematical knowledge and techniques required, and then apply these to reach a satisfactory solution. Perhaps the issue that exists is not a lack of fundamental knowledge and ability, but an inability to apply mathematics to solve unfamiliar and conceptual problems. This is somewhat analogous with what is now being noted in mathematics and physics.[3]






Finally, we analysed the effect of an A-level qualification in mathematics on overall degree classification. The model developed suggests that in one institution, those without a mathematics A-level are predicted to do better than those with a grade C but worse than those with a grade B; in the other, there is no obvious consistent pattern between A-level mathematics and degree attainment over time, however, those with grades A and B are seen to do marginally better overall. Significantly, there is a greater variation amongst those without A-level mathematics, which requires further research.

### Tackling the underlying problems

We have already seen that teaching mathematics to chemistry students is usually focused in the first year. Universities are increasingly offering additional support to aid student learning, although the extent to which students make use of these is not clear.[6]

Further issues were identified with the course structure not allowing students sufficient opportunities to develop their mathematical skills through application, and the reliance upon summative examinations as a means of assessing mathematical skills. Staff felt there was sufficient additional support, but that the students themselves needed to do more. This again is an interesting finding, particularly since a number of reports[5] indicate the students themselves do not feel there is an issue with their mathematical skills and knowledge, again indicating a mismatch between staff and student views.

It was interesting to consider the teaching of mathematics to chemistry students more broadly across the sector. There can be a tendency towards the delivery approach of: 'Don't worry about the origin of the mathematics, put the numbers into this set of equations and you will get the result you need.' This approach relies heavily on rote learning and does not develop an understanding of what happens if the situation changes or the problem is structured differently. The consequence is that students do not understand, or appreciate, the key underpinning mathematical ideas and how these apply in practice, leading to an inability to see how they might be applied to new problems. Letting students see how such results can be derived, even as an extension activity, allows them to be exposed to the basis of an idea they can draw upon in the future. What we are advocating is that the mathematics in chemistry should not be hidden and results merely presented. Instead, it should be embraced and explained, not necessarily

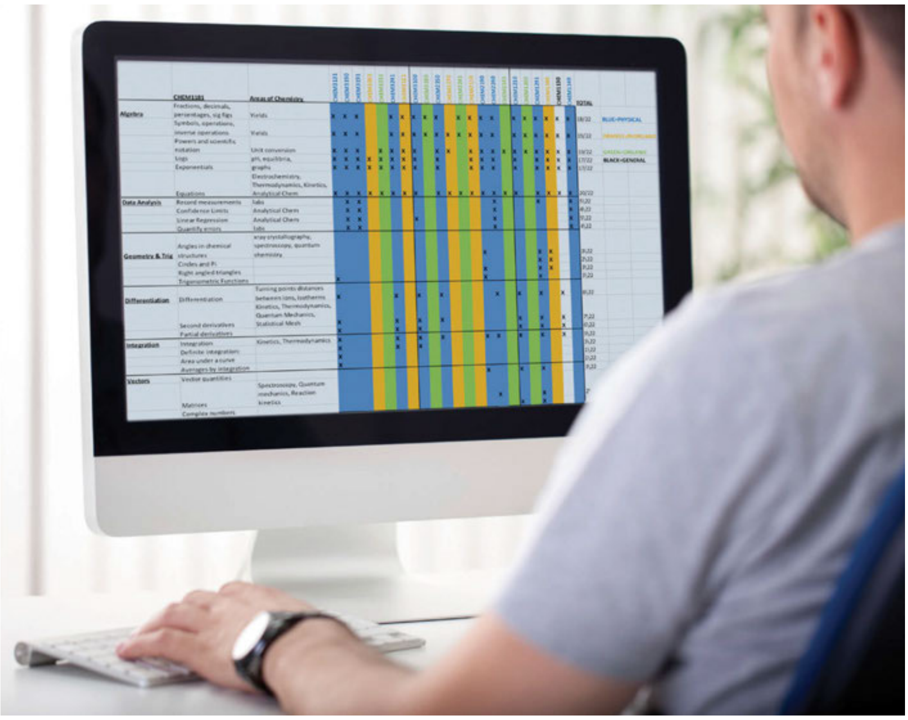




**Figure 1: Mapping mathematical concepts within a typical three-year chemistry degree. This data is available in the online version of this article: http://rsc.li/1BOwqBX**

for assessment (and this can be made clear to students), but to make it clear that mathematics is important within chemistry and a technique that needs to be mastered.

## Developing support resources

During our research, it became apparent that in many cases, teaching the applications of mathematics to problems in chemistry takes place after basic mathematical ideas have been introduced, and usually as a separate module.

We identified a need to create a resource that would not only provide an overview of key mathematical ideas and concepts, but would also give examples of the kinds of chemistry problems that require mathematics. Working again with interns, we chose to develop an ebook (integrating print and digital content), designed to help first year chemistry students making the transition to university. We did not set out to replace existing text books. Our ebook provides students with an additional resource in a quick reference style, allowing them to explore key mathematical ideas quickly and succinctly.[11,12] Its key feature is that it contains numerous examples demonstrating how the mathematics they learn is applied directly within a chemistry context. Most significantly, it has been developed as a partnership between chemists and mathematicians, and is based on findings from our research. The ebook is currently being used by first year students at the Universities of Birmingham and Leeds and is available for free download.[11,12]

## Emerging recommendations

Our work, in addition to the development of the ebook, has identified a number of recommendations or areas universities might like to consider when seeking to support chemistry students with learning mathematics:

1. The importance of mathematics to chemistry should not be hidden. Staff surveyed indicated that A-level mathematics should not be compulsory for students to study chemistry; however, the importance of mathematics, and the desirability for A-level, should be advertised to potential future learners during school/college visits and in the recruitment prospectus.
2. Opportunities for undergraduate students to apply mathematics to problems in chemistry should be offered alongside sessions that introduce the introductory mathematical ideas, perhaps through tutorials or peer-assisted learning sessions.
3. There should be continual opportunities for students to apply and develop their mathematical skills throughout all aspects of their course (for example laboratories and lecture courses). In doing so, staff need to clarify why the mathematical techniques are important, and what the key mathematical ideas are to allow cross-referencing and independent study.
4. Universities should consider when the teaching of mathematical ideas might best be introduced: is all upfront appropriate, or should they be distributed throughout the undergraduate degree programme?
5. At key times, students should be directed to other forms of support that are available, for example, mathematics support centres, and their need to attend made clear.
6. Finally, key mathematical ideas, concepts and results should not be hidden from students, but should be presented in ways that they can understand and appreciate.

Tackling the mathematics problem within any discipline will ultimately require changes to the curriculum, and there is much to learn from how other disciplines are beginning to address this issue. For us, a key feature in the success of our work, and the institutional enhancements that will result, has been the partnership between mathematicians and chemists; it is one we would recommend others explore.

**Acknowledgements**
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*Michael Grove is a Senior Lecturer and Director of the STEM Education Centre at the University of Birmingham. Samantha Pugh is a Lecturer in STEM Education and Teaching Enhancement at the University of Leeds*

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# A15. Progression within mathematics degree programmes

Croft, A.C. & **Grove, M.J.** (2015). Progression within mathematics degree programmes. In Grove M. J., Croft A. C., Kyle J. & Lawson D. A. (Eds.), *Transitions in Undergraduate Mathematics Education* (pp. 173–190). Birmingham, UK: University of Birmingham and Higher Education Academy.

# Chapter 13: Progression within mathematics degree programmes

**Tony Croft & Michael Grove**

## Abstract

Several independent research projects report that the enjoyment of mathematics by many undergraduate mathematicians decreases as they progress through their degree programme and this decrease is accompanied by increasing disillusionment and disengagement with their course and alienation from mathematics itself. These are students who *choose* to study mathematics at university and who are relatively well-qualified. Moreover, it is often the case that students who report such feelings are not failing students – indeed many are doing rather well. Of course, many other students find their undergraduate experience of mathematics to be extremely rewarding but the prevalence of studies reporting disaffection suggests that this is an issue worthy of exploration within a book on transitional issues affecting undergraduate mathematicians.

This chapter will review the evidence for this phenomenon and unpick the reasons students give for their changes in attitude to mathematics. After establishing the context for the chapter we present a brief review of the literature in this field. The evidence suggests that this state of affairs can be attributed, at least in part, to the mismatch between students' hopes, expectations and aspirations and the reality of learning mathematics at university level. Sometimes, traditional pedagogies and practices can exacerbate this situation. We will go on to provide several examples of ways in which some lecturers and departments have attempted to modify practices in order to improve the student experience of university mathematics. We summarise the findings of selective activities and projects that provide pointers in the hope that they might inspire or provoke a discussion amongst individual lecturers and more widely within departments about ways in which disillusionment, disengagement and alienation might be ameliorated so that the experience of undergraduate mathematics is truly rewarding for all who choose to study it.

## Introduction and context

The 'sophomore slump' is a well-documented phenomenon whereby students in the second year of their university studies can feel the 'second-year blues'. It has been the focus of a number of studies, although these have not specifically dealt with second year mathematics undergraduates. A recent, substantial contribution to the literature is that of Thompson et al. (2013) which is described as a first attempt in UK higher education to investigate the second year experience and issues associated with it. Of course students in their first year of study can be unhappy too. During the first year some fail to adjust to university life, both socially and academically. They perhaps struggle with the depth and breadth of the mathematical material that is expected of them, or fail to adapt to new approaches to learning. They might experience challenges living away from home for the first time or establishing new friendship groups. Such long-standing challenges at the school/university transition are not only well understood, but have received considerable attention: academically, through diagnostic testing (see for example MathsTeam, undated), first-year curriculum change (Savage & Hawkes, 2000:3), provision of additional support (see Chapter 4 in this book); and socially, through university experience days, buddying schemes, students union activities, halls of residence activities and so on. Moving into year 2, any initial 'novelty' and enthusiasm felt for university life has perhaps long-since waned; there is a realisation that the work is getting harder and requires an increasing proportion of a student's time coupled with the expectation that students are more independent and mature learners. The stakes are also starting to get higher; in the majority of universities performance in the second year contributes towards final degree classification. Thompson et al. (2013) discuss the wide range of factors which contribute to disengagement and underperformance and argue that *"the second year is a pivotal stage in the student life cycle and that academic and support staff need to be sensitive to the complex range of issues students may face in their second year"*.

Whilst students from any discipline may experience this sophomore slump, for many mathematics undergraduates the problems can be severe and can persist through the remainder of their degree programme to the extent that they describe negative feelings about their mathematics degrees even after graduation (Goulding, Hatch & Rodd, 2003). We argue that there are reasons why mathematics students might be particularly affected:

a) Some question the purpose of studying abstract concepts of which they have little understanding, and see little in the way of application of much of the mathematics they are learning; many come to realise, quite rightly, that they will never use many of these specific mathematical techniques again.

One might argue that this is true of many academic disciplines studied at university; however the evidence from a study we cite later suggests that an important reason for students choosing to study mathematics is because they believe the mathematics they will learn will be useful and that they will use it to solve real world problems and yet many find that this is not necessarily the case.

b) As we cite below, students report feelings of alienation, they describe narratives of existing on the margins and not feeling part of a learning community.

We shall point to research which suggests that the ways in which mathematics teaching is traditionally 'delivered' to students can exacerbate such feelings for some, though not all.

c) Less academic support may be available in year 2 during a period in which the mathematics may, depending upon the type of institution in which it is being studied, become increasingly formal and abstract. Whilst a reduction in support may be a feature of the second year for students of any discipline, mathematicians in particular may no longer have access to mathematics support centres (established principally for first year students) which they may have relied upon (sometimes heavily) during their first year. Students report that there is less in the way of traditional tutorial provision. Frequently, closed-book final examinations are the predominant mode of assessment.

We would like to emphasise that such negative feelings, whilst commonly reported, are not ubiquitous, and for many students, university mathematics continues to provide challenge, inspiration and a continuing love of the discipline. For these students the curriculum and the traditions and practices of university mathematics departments are not alien and the students thrive. The focus of this chapter though is not upon the students who are enjoying their courses and thriving mathematically – they will continue to do well. Rather, in the spirit of encouraging a more inclusive mathematical experience, we focus here on those who are not. Evidence that there are a sufficient number of such students to merit consideration of this issue at all can be found in studies such as that by Brown, Macrae, Rodd and Wiliam (2005) described in more detail below, which found that in a survey of undergraduate mathematicians (N=150) in two English universities, over 20% failed two or more modules (out of six) in their first semester examinations in year 2.

## Literature review

In an effort to understand better the nature of the challenges at second year level we have reviewed a range of relevant research studies. From these we have extracted five themes which are common across many and which we discuss further. Of course, some of these themes will have resonance in disciplines other than mathematics, but where there are mathematics specific issues we draw attention to these:

1. The importance of a sense of belonging and inclusion in a peer or departmental community and the learning and teaching relationship between staff and students; alienated students refer to lecturers' lack of interest in them.
2. The quality of teaching – often cited by students as a reason why they disengage; poor teaching means that advanced topics are made even harder to assimilate.
3. The nature of university mathematics and the pedagogic practices of departments and of individual staff members which can often fail to align with the preferred learning styles of students.
4. Many students are encouraged or choose to study mathematics because they were 'good at it' when at school. This may change when they get to university, when for some, an important motivating factor (i.e. success) is removed. Others, even very successful ones, do not have a strong interest in mathematics, but see the acquisition of a mathematics degree as an enabler for their future (non-mathematical) careers.

5. The apparent lack of relevance and application of much of the mathematics taught in a context wherein students have been encouraged to study mathematics because of its usefulness in life and in the workplace.

We now consider each of these themes in turn.

**The sense of belonging and staff/student relationships**

Our starting point is the study Student Experiences of Undergraduate Mathematics (SEUM) (Brown et al., 2005) which examined progress and changing attitudes to mathematics amongst a cohort of well-qualified single honours mathematicians in two research-intensive English universities. Feeling part of a mathematical community emerged as a crucial factor in the student experience, and in the SEUM project, this community focused on a particular physical space within one of the participating universities. Within this space students could not only work together but *"could 'catch' lecturers going to and from* [their] *offices, as well as make formal and informal appointments to discuss various concerns"*. So feeling part of a mathematical community involves both opportunities for interactions with other students and, crucially, with staff.

Croft, Solomon and Bright (2008b), motivated by the SEUM project, believed that there may be scope for improvement in mathematics support beyond year one of a degree programme. In their study, through focus groups they explored which forms of support are accessed by students, which forms they find inaccessible, their views on support provided formally and on the informal networks that they develop with their peers. Focus groups were held in two research-intensive universities A and B. At University A student volunteers were selected from amongst those who had achieved at least an upper second-class score (i.e. greater than 60% overall) in their first year. Two focus groups, each of five students took place in University A. At University B, all second year mathematics students were invited to volunteer and two groups of two and three students respectively were interviewed. All the students in the focus groups in University A were positive about their university experience. On the other hand, when discussing mathematics at university, students in the second made the point that they didn't feel part of the mathematics community:

> *"Here you're just kind of a number, or one of a crowd. You feel quite anonymous and have all this learning to do".*
>
> Croft et al. (2008b:25)

When asked about their sources of support it became apparent that the support they were obtaining from their peers was highly valued. Students in both universities were asked to whom they would turn first for support:

> *"yeah I reckon my friends will be the first point of call".*
>
> Croft et al. (2008b:26)

> *"[working with others] that's the most fruitful situation in which I work – and sit with a group of friends".*
>
> Croft et al. (2008b:26)

Similarly, Brown et al. (2005) reported that students who had more positive attitudes to studying mathematics were those who shared their ideas and problems with other students.

*In Mathematical Literacy – Developing identities of inclusion*, Solomon (2009) has a chapter devoted to the experiences of undergraduate mathematicians beyond their first year. She reports upon how the students she interviewed positioned themselves in relation to mathematics, their tutors and peers on the course, for example Emma who always positions herself as 'second-best' but goes on to describe her tutor's assessment of her:

> *"my tutor seems to have high expectations of me…my tutor has more faith in me than I do".*
>
> Solomon (2009:125)

Solomon reports that in her studies, as in other work she refers to, the importance for women of relationships with tutors comes to the fore. Emma goes on:

> *"It helps because whenever I go to see him when I'm stuck he doesn't think "well I'm not going to help here – she can figure it out for herself", he's always like, "I'm going to help her then she can get there"".*
>
> Solomon (2009:126)

Unfortunately, not all students reported the same supportive tutors – in the same study Jess reports:

> *"my tutor laughs at me".*
>
> Solomon (2009:126)

Rather than being seen as humorous, her fellow students show expressions of sympathy. Even inadvertent or throw-away remarks can inflict damage in ways of which tutors are probably unaware.

Goulding et al. (2003) report a study in which they surveyed 173 students on ten postgraduate teacher training courses (PGCE). These students had attended 65 different universities for their first degree that was either mathematics or one strongly related to mathematics. They were questioned about their undergraduate experiences. Some described the challenge and rigour of university mathematics as interesting and rewarding. Thirty-nine students commented explicitly about their development of understanding during their undergraduate degree. The majority of these students described this as a struggle but one which eventually gave rise to feelings of satisfaction; however, almost as many had been unsuccessful, claiming to have achieved *"little or no understanding"*:

> *"it was a struggle to maintain enjoyment in the subject when I never felt completely satisfied I understood the concepts in front of me".*
>
> Goulding et al. (2003:370)

Students in this study, as in the others, all recognise the need to work independently, but some felt abandoned, with others relying on informal peer support mechanisms:

> *"Most lecturers and my tutor were completely unapproachable – you couldn't ask questions during lectures and felt very alone".*
>
> Goulding et al. (2003:371)

The importance of supportive staff and peer communities should not be underestimated and is a recurring theme in many studies and one to which we shall return.

**The quality of teaching**

Inglis, Croft & Matthews (2012) surveyed the views of 428 mathematics graduates, 85% of whom had graduated from 'research intensive' universities. Their aim was to ask mathematics graduates who had been in the workplace for around two to three years to reflect on their undergraduate experience to ascertain the extent to which the undergraduate curriculum prepared students for the workplace. The issue of teaching quality attracted a number of suggestions although the overall message was variable: many students reported an excellent teaching experience, but others clearly felt there was much room for improvement. The general message was that participants would have liked to receive more in the way of teaching than lecturing, more opportunities for problem solving sessions, and more opportunities to discuss mathematics with their lecturers.

In the survey by Goulding et al. (2003) 23% chose to offer comments about the quality of teaching. Most were very critical of their teachers and their teaching methods, particularly those with an over-didactic style:

> *"To sit taking meaningless notes all day was just too much…I feel that lectures could have been replaced with handed out notes and some real teaching allowed to take place".*
>
> Goulding et al. (2003:372)

As a consequence of this lack of *"real teaching"* feelings of frustration were common, with many reporting their undergraduate study as a negative or lonely experience:

> *"I hated it most of the time…it became difficult to enjoy some of the maths modules if you were struggling and couldn't get any help".*
>
> Goulding et al. (2003:373)

**University mathematics, pedagogic practices and students' learning styles**

In their study of twelve first-year mathematics undergraduate students, also in a (different from SEUM) research-intensive English university, Daskalogianni and Simpson (2002) refer to *"cooling-off"*. Cooling-off students are those who come to university from school with a positive attitude to mathematics. They find themselves in a learning environment which is very different from the one in which they have previously functioned successfully:

> *"the experienced mismatch between their beliefs about the nature of mathematics and its rigorous university character soon makes them lose interest in mathematics and develop a negative attitude towards it."*
>
> Daskalogianni & Simpson (2002)

They sum up:

> *"It is then up to the students themselves* [our emphasis] *to either recover from that [cooling off] phase or give up and lose not only their interest in mathematics but even their interest in the course and develop a cooling-out behaviour which is very intense in its signs, very difficult to change and might even result in drop-out from the course."*
>
> Daskalogianni & Simpson (2002)

Writing about pedagogic practices Solomon (2009) notes that:

> *"the fast pace of delivery in lectures meant that [often] the students were simply writing notes without having the time to think about what they were writing. This appears to contribute to a sense of disempowerment."*
>
> Solomon (2009:126)

This is particularly poignant given that lecturers say they want students to be independent, and at the same time (some) would appear to disempower the very students they want to be independent (see Chapter 6 in this book). So what might a good lecture look like? Students commonly cite a desire for a 'good set of notes' but Solomon's student quotes offer some further insight:

> "[a good lecture should leave the student] *actually wanting to go home and do the homework rather than "I've got to do that homework that I know I'm not going to be able to do"".*
>
> Solomon (2009:126)

It is not about spoon-feeding or dumbing down. Students expect to have to work for their mathematics degree; they know they are expected to be independent, they do not expect to understand everything in a lecture; however they must be given sufficient support and encouragement to enable them to think that putting in effort on their own is going to be worthwhile. What constitutes 'sufficient' support is open to debate, and colleagues will have a range of opinions on this matter, but we would suggest a level of complacency amongst those who argue that there is little room for improvement in learning resources or teaching practices.

Some students find assessment practices too to be a source of alienation. It is interesting here to note the findings from the MUMAP (Mapping University Mathematics Assessment Practices) Project (Iannone & Simpson, 2013) which examined undergraduate mathematics assessment practices scrutinising 1843 modules from 43 degree courses. The project concluded that assessment of university mathematics in the UK is still dominated by closed-book final examination with over one quarter of modules assessed solely by closed-book examination, and about 70% of modules using closed-book examinations for more than 75% of the final module mark.

**Students becoming demotivated when no longer successful or interested**

Several studies found students who described how much harder they found it to understand new material in year 2. In Croft et al. (2008b) one student mentioned they had much less supervision, tutorials were different in terms of group size and so they felt there to be less support:

> *"This is the first year I've gone into an exam and had questions I can't actually answer, because I've always been able to do all of the paper. There's a lot of material this time around, but unless you understand it, it's not really interesting."*
>
> Croft et al. (2008b:25)

The SEUM project report notes:

> *"success in the subject at A-level was the major reason for choosing mathematics as a single honours course. When some no longer perceived themselves to be particularly successful there was little to motivate them to continue studying except a need to maintain self-esteem and gain credentials."*
>
> Brown et al. (2005:3)

Doubtless anyone reading this will expect material in the second year of a mathematics degree to become more demanding but the point is to recognise the challenges that this causes for students and to ensure that mechanisms are in place to develop the skills of independent learning that are required, to encourage students to find and develop their own supporting mechanisms and to develop into robust learners.

**The apparent lack of relevance**

Inglis et al. (2012) citing Thomlinson, Challis and Robinson (2009) compared the outcomes of a survey of the expectations of 223 incoming undergraduates with the results of a survey of 428 graduates. Thomlinson et al. (2009) had found that 93% of incoming undergraduates had expected to develop skill in applying mathematics to real world problems and 95% expected this skill to be important in their future lives. However Inglis et al. (2012) report that only 62% of graduates felt that this had been achieved during their undergraduate studies. One respondent wrote:

> *"My only issue relates to real world experiences as I feel that this is where mathematics students have been let down. There is little if any mention of how to link mathematics to the real world of work."*
>
> Inglis et al. (2012:19)

This resonates with earlier findings in the SEUM study: with specific reference to the relevance of the content being studied, these students had been led to believe that it would be:

> *"useful for life in general and for possible future careers".*
>
> Brown et al. (2005)

As the course progressed:

> *"many of these same students reported their disappointment that the mathematics they were now learning had become so pure as to have no possible application: "I thought I was lucky to realise the importance of maths and to be able to study it at university but now I can't imagine ever using it in any job I'll ever do…"".*
>
> Brown et al. (2005:4)

However it is important to balance this view with alternative perspectives reported by some. For example:

> *"it is satisfying to learn mathematics for its own sake – don't try and make it more applied."*
>
> Inglis et al. (2012:22)

and:

> *"for me, the most worthwhile aspects of the degree were those modules I took because they interested me. Please include the pure modules that may not seem applicable to most careers."*
>
> Inglis et al. (2012:22)

Of course, the nature of mathematics degrees varies greatly within the sector with some offering courses which are more formal and abstract, some offering quite different proportions of pure and applied modules, and others (many of the newer universities fall into this category) offering courses which are much more orientated to applications and to the workplace (see for example Robinson, Challis & Thomlinson, 2010). Furthermore, many of the exciting real-world applications of mathematics can only be accessed through postgraduate study and perhaps this is not always made clear. However, the point here is that perhaps the particular type of course is not always well communicated to prospective students and a question for the community is how the apparent mismatch can be addressed.

Having briefly reviewed a selection of the literature relevant to the second-year university mathematics experience, the following section considers some ways in which these issues might start to be tackled.

## Enhancing the second year experience

In this section we highlight several initiatives that have been instigated to enhance the second year experience. We do not suggest that these provide panaceas for the solution of the problems highlighted, but they provide pointers to possible ways forward. They include creating spaces within which students are encouraged to work together and support each other to develop learning communities, establishment of formal peer support schemes, involving students in curriculum development, encouraging more opportunities for staff/student interactions, and increasing exposure to real-world applications and contexts.

### Creating spaces for students within mathematics departments

A finding of the SEUM study related to the extent to which students felt part of a mathematical community. The project noted:

> *"in one institution, students had their own mathematics study area comprising three sub-areas: an open plan section with tables and chairs; an area with easy chairs and coffee tables; and a cafeteria. Off these areas were staff offices and students could 'catch' lecturers going to and from these offices, as well as make formal and informal appointments to discuss various concerns."*
>
> Brown et al. (2005:6)

In the second institution there was limited social space for mathematics (and further, at that institution many students lived at home), and:

> *"this resulted in a sense of isolation with many of the students reporting difficulty in making friends."*
>
> Brown et al. (2005)

In a survey by Croft, Grove and Bright (2008a) students were asked about the benefits of providing them with social learning space in the department:

> *"When you go to work [in a dedicated social learning space] the people in there are going to be doing the same stuff as you anyway so you get help with each other."*
>
> Croft et al. (2008a:13)

In this student's university, space was then found within the School of Mathematics to provide a dedicated area for second and third year undergraduates to work. This reflects an increasing trend by universities, certainly within the UK, and one which seems to be welcomed by students, to provide more extensive social study space for their use.

**Peer support**

Often friendship groups formed in year 1 are maintained throughout the degree and are mutually supportive. However not all students make friends with students on the same course, and this can be a cause of academic isolation. The formalisation of peer support forms a way in which a department can offer support and at the same time enhance the student experience. This aspect featured in the results of the graduate survey by Inglis et al. (2012). Fifteen out of sixteen unsolicited references to peer support referred to the benefits:

> *"perhaps we should be allocated to study groups to assist those who don't naturally find friends on the course and end up working alone."*
>
> Inglis et al. (2012:2)

A peer-assisted learning (PAL) scheme was implemented at Loughborough University in 2011/12 to address the difficulties experienced by second year students. Students who had successfully completed two specific second year modules volunteered and were provided with training to act as 'Student Leaders' in weekly PAL sessions. Around half of the second year cohort chose to engage with the scheme and those who attended the PAL sessions had higher achievement in their final module examinations even after controlling statistically for prior attainment and lecture attendance. Of course, not all students wanted to attend PAL sessions, some because they preferred to work alone and could succeed independently. Those that did attend found the PAL sessions to be informal and welcoming and involved discussion of mathematical topics that had previously been suggested by the PAL participants.

The preceding discussion highlights the non-homogeneity of student groups in terms of their preferred learning styles, and whether they prefer to learn mathematics with others or on their own. Attempts to address problems of disengagement and alienation must be sensitive to these differences and try to present a portfolio of opportunities sufficient to meet the needs of diverse cohorts.

**Involving students in expert communities**

In recent years there have been calls to the higher education community to involve students more in the planning and design of courses (see for example Kay, Marshall & Norton, 2007). The SYMBoL (Second Year Maths BeyOnd Lectures) project based at Loughborough University in 2011 did just that. Four students who had successfully completed the second year of the single honours course in mathematics were employed as interns for a six-week period during the summer. Their focus was upon two historically-problematic second year mathematics modules. They had several roles:

- To act as intermediaries between their peers and staff gathering information about teaching strategies that the students perceived to work well, suggesting improvements, and alternative ways of doing things.
- To work with staff, scrutinising the modules' resources and suggesting ways in which these might be improved.
- To develop further resources of their own, under the guidance of the module leaders, which would be (and were) made available to future cohorts.

Findings have been reported in Croft, Duah and Loch (2013) and include the ways in which the interns were inculcated into the mathematical community and the nature of their relationship with staff changed for the better. Through their mutual engagement staff and interns engaged in a mathematical discourse in ways that normal lectures and tutorials do not make possible: as well as building better relationships with staff and becoming part of a mathematical community the interns involved reported deeper mathematical understanding and confidence in their own abilities. Staff acknowledged that students can bring a new dimension to teaching and learning discourses:

> *"[Students probably have] more knowledge of where exactly the students are struggling. Pointing exactly at the right places where the lecturer might think the students have understood when they haven't actually because the feedback loop is not as closed as it should be."*
>
> Croft et al. (2013:1051)

In this sense, as well as providing opportunities for some second year students, we see the initiative as encouraging continuing professional development of staff and a means for at least some improvement in alignment between student and staff expectations.

In a more generic context while employability audits of undergraduate programmes have existed for some time, these have typically been undertaken by academic staff rather than students. The University of Exeter, in a student-led project undertaken in collaboration between students, graduate employers and staff (Cooper, 2012), carried out an audit of the extent to which support for the development of employability skills is embedded within the mathematics, computer science and engineering degree programmes. The process was overseen by a paid focus group of students working over a period of six weeks to audit current provision and make recommendations for how employability skills might be enhanced. All mathematics and engineering students (some 300 in total) from across all year groups were invited to participate through a questionnaire to obtain a wider student perspective; 49 students responded.

Through a blog established in support of the project, updated by both staff and students, their views on the process were captured, and this was further supplemented by the creation of a 'Creative Learning Journey' which formed a multimedia staff and student perspective on the process. While established to help students develop their employability skills, through both undertaking a project and enabling revisions to existing provision to be suggested (for example one outcome has been the design of a mathematics group project module), students have been able to make a direct contribution to their learning experience which they have valued:

> *"Its* [sic] *been a very productive 6 weeks and we feel the contributions we have made will be valuable in improving the degree programme."*
>
> Prince & Neale (2011)

Through the National HE STEM Programme, the Student-Led Employability Audit was extended to five further universities, and at the University of Manchester this was implemented to audit undergraduate degrees within the School of Mathematics. A similar outcome to that at Exeter was that students produced a report, recommending both major and minor changes to the provision they experience, some of which were implemented in time for the 2012/13 academic year. The key outcome relevant here is the extent to which students felt involved in the process of developing and enhancing their own learning, recognised their role within the process, and had opportunities to engage in dialogue with staff about this.

While these two activities form specific examples, they represent a more general point of being approaches that enable students to contribute to the development of their own learning and feel that they are making a contribution to enhancing the practice of their department. It might be argued that the immediate benefits of such activities are limited to the relatively small number of students involved and do not transfer to the wider student body. But in fact we believe that some benefits do transfer, although perhaps in more subtle ways. Firstly, there is little doubt that this professional development experience for the small number of staff directly involved has given them new insights into the difficulties and perceptions of the students; in turn this is likely to impact gradually on their own teaching practices. There are also the benefits perceived by other (non involved) students in that the department is seen to be listening to their concerns, taking these seriously through meaningful action, and that modifications might ultimately be made as a consequence of their work.

**Developing (informal) staff student communities**

A number of mathematical sciences departments have established 'Maths Arcades' – drop in sessions where students can play a range of strategy games and puzzles with each other and with academic members of staff (see for example Bradshaw & Rowlett, 2012). Maths Arcades aim to simultaneously support those learners who may be struggling and test and challenge more confident learners. One of their key features, however, is to enable greater staff-student interaction in an informal, but mathematical, context.

While Maths Arcades are a new initiative, certainly within the UK, initial evaluations have shown that one of the key aspects students value is the increased opportunities they provide to interact with members of academic staff:

> *"I like to go to the Maths Arcade because all of my tutors attend it".*
>
> Bradshaw (2012:12)

> *"[It is] a really good way to meet people and get to know the lecturers in a more informal environment"*
>
> Bradshaw (2012:12)

And staff report complementary views:

> *"I thoroughly enjoyed playing against the students where they had as much chance of winning as I did. It allowed us to interact in a more relaxed but equally intellectual way."*
>
> Levesley (2012:23)

Maths Arcades have prompted students who have not engaged with drop-in mathematics support to seek support from tutors, and increased engagement between student cohorts has been reported by staff:

> *"…the more that students see mathematical conversations happening between staff and students, the more they realise that they too can ask questions…The games were used and maths conversations were started ("can I ask you a question?") by students who had not attended the traditional drop in sessions. There was also interaction between staff and second year students and between the year groups."*
>
> Barton (2012:27)

As a consequence of running Maths Arcades, universities have recognised the concept of games and puzzles to enhance student problem solving skills, and as such, have implemented these into the curriculum:

> *"In addition, the puzzles and games have been incorporated into a second year mathematics module that aims to develop problem-solving skills. Students study the various games and puzzles, in particular by playing the games against other students, and the discussion of the games themselves leads to understanding of the strategies required to play effectively."*
>
> Chadwick (2012:17)

**Context and problem based learning**

We have already commented that many, but by no means all, mathematics graduates would welcome increased exposure to more real-world applications of mathematics. There is no doubt that formulating and solving problems is a core part of all undergraduate mathematical sciences provision, but what is less well embedded, particularly when compared to disciplines like, for example chemistry (Belt & Overton, 2007), is the context within which mathematics is applied to solve problems (context based learning). Many of the recruitment talks and events students experience while making their university choices highlight examples of how mathematics can help solve key global challenges or, for example, where mathematics can be applied in appealing fields such as sport or music technology, but quite often this is the last time such applications will be mentioned during their university studies; for some, this can lead to a mis-match between their expectations and the realities of studying mathematics.

Some mathematics departments have sought to implement ways for students to experience mathematics within a range of applied contexts. Placements, whereby students spend a period of time working within business or industry as part of their degree programme, have been offered for many years but as noted by the Science Council (Mellors-Bourne, 2011) while there is not generally an issue in the supply of placement opportunities an *"increasingly significant proportion of sandwich course students are reluctant to undertake long placements (partly because many HEIs charge at half fee level)"*. Despite this, placements offer a range of benefits including not only the chance for the student to develop essential employability skills, but they can also increase student motivation by demonstrating how they can apply their skills and knowledge successfully in business and industry. In the past, industrial placements would typically have been a year in duration but there now exist a range of models which allow students to access placement opportunities in a more flexible and tailored manner ((see Mann, 2012) for a review of models in mathematics).

Where it has not proved possible or practicable to implement placement models, mathematics departments have found alternative mechanisms for students to gain more context-based experience. A number of departments have, for many years, offered postgraduate level industry study groups whereby representatives from industry work with mathematicians in a structured manner on current workplace problems. Variations upon this model have been adopted by a number of mathematics departments where undergraduate students work collaboratively on employer-defined problems and case studies as part of their programmes of study. Students not only engage with current and meaningful real-world problems, but employers also typically have a role in contributing to delivery and supporting assessment, which means students develop relationships with employers in a manner that allows them to discuss the relevance and applications of mathematics. Recognising that not all mathematics departments have access to a wide range of employers, there has been significant work in developing a 'bank' of freely accessible industrial problems which academics can use with their students (see for example, Benjamin, Homer, Lawry & Rossiter, 2012). Such forms of problem based learning are more interactive, representing a move towards experiential rather than didactic learning, and as a consequence students have increased opportunity to engage with members of staff.

## Concluding remarks

In this Chapter we have looked particularly at published evidence which suggests that the academic experience of many, but by no means all, second year mathematics undergraduates is less rewarding than it could be. Doubtless some of the issues we highlight affect students in other years and in other disciplines too. However our focus here has been the second year experience. We have suggested several ways in which this experience could be enhanced. We have provided details of these not as a prescription but rather with the intention that they encourage reflection by mathematics staff on practices within their own departments:

- Are there issues like the ones described here within my own department? How would I know?
- Is there scope for improvement of practice within my own department?
- Are the full range of students that we recruit best served by our teaching and learning practices, by our curriculum and by the supporting infrastructure we provide?
- When we promote our courses to prospective students are we clear about the nature of these courses and particularly what makes them distinctive in our institution?
- What steps, if any, are individuals and departments in other universities taking to address these issues?

If individuals, groups of staff and whole departments reflect seriously on these questions, and practices evolve accordingly, the experience of all their students will be enhanced. As many of the chapters in this book affirm, there is a growing corpus of literature and many colleagues and interest groups to support staff in this journey.

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# A16. Mathematical modelling and problem solving: High-level skills for higher education STEM students

Savage, M.D. & **Grove, M.J.** (2015). Mathematical modelling and problem solving: High-level skills for higher education STEM students. In Grove, M.J., Croft, A.C., Kyle, J. and Lawson, D.A. (Eds.) *Transitions in undergraduate Mathematics Education* (pp.). Birmingham, UK: University of Birmingham and Higher Education Academy.

# Chapter 9: Mathematical modelling and problem solving in real-world physical situations

**Mike Savage & Michael Grove**


## Abstract

There are many well documented issues concerning the mathematical preparedness of students making the transition to higher education within not only the mathematical sciences, but also chemistry, physics and engineering. In this chapter we consider a further emerging aspect of this problem where, even with an increased numbers of students applying to study these disciplines, many of whom have the highest grades, students often struggle to apply the mathematics they have learned to model physical situations and solve unfamiliar problems.

While this may be attributed to the mathematical preparation students receive prior to university entry, the issue in question is how universities help their students develop these skills to aid both progression within their programmes of study, and their transition to employment or research. Here we discuss the evidence of incoming undergraduates lack of experience of mathematical modelling and problem solving before focusing upon a particular example of how the University of Leeds has sought to address this issue via a new first year undergraduate mechanics module.


## Introduction and definitions

As has been observed (Schoenfeld, 1992) 'problems' and 'problem solving' have had multiple and often contradictory meanings through the years. In this chapter we focus on real-world physical problems and in this section we set out our definitions[1].

1 Chapter 8 discusses problem solving from another perspective.

Mathematical modelling and problem solving (MMPS) are two distinct, but vitally important skills: 'mathematical modelling' and 'mathematical problem solving'. These are essential skills for problem solvers who address real world problems such as:

- How high above the earth should a geostationary satellite be positioned?
- Determine the dynamics of Felix Baumgartner's world record skydive from 39km above the Earth.

These examples, which originally formed genuine research problems, can only be tackled successfully by attempting to understand a physical situation – in essence developing a model (mathematical modelling) and then trying to understand that model through a rigorous mathematical analysis (problem solving). The skills of mathematical modelling and mathematical problem solving are not only essential for success within the undergraduate mathematical sciences, and indeed science, technology, engineering and mathematics (STEM) programmes, but they form skills that often must be mastered for students to function successfully within the workplace:

> *"The development and application of mathematical models is very common and occurs across a range of industries."*
>
> ACME (2011:19)

Mathematical modelling and problem solving can perhaps be best understood through a modelling and problem-solving cycle, illustrated in Figure 9.1, which represents a systematic way of undertaking a mathematical investigation. The cycle comprises three fundamental stages: 1) Set up a model; 2) solve the mathematical problem; and 3) interpret and validate the solution – following which the model may be refined and the cycle repeated (Savage & Williams, 1990).

The starting point for the cycle is a real-world problem, for example in nature, business, or industry, which has not yet been transformed into a mathematical problem. This transfer from a real-world problem into a mathematical problem takes place through the modelling process. This simplifies the problem by making assumptions, while ensuring the essential features are retained. Indeed, determining exactly what the essential features are, for any given situation, is itself a fundamental skill that can only be developed through experience. This results in a mathematical description that can then be solved using mathematical or computational techniques.

Once a solution of the mathematical problem has been derived and interpreted, it is then validated against real data or experiment as appropriate. Should this solution prove to be inaccurate then the model has to be refined by changing one or more of the assumptions and a more accurate solution sought by going around the modelling cycle once again.

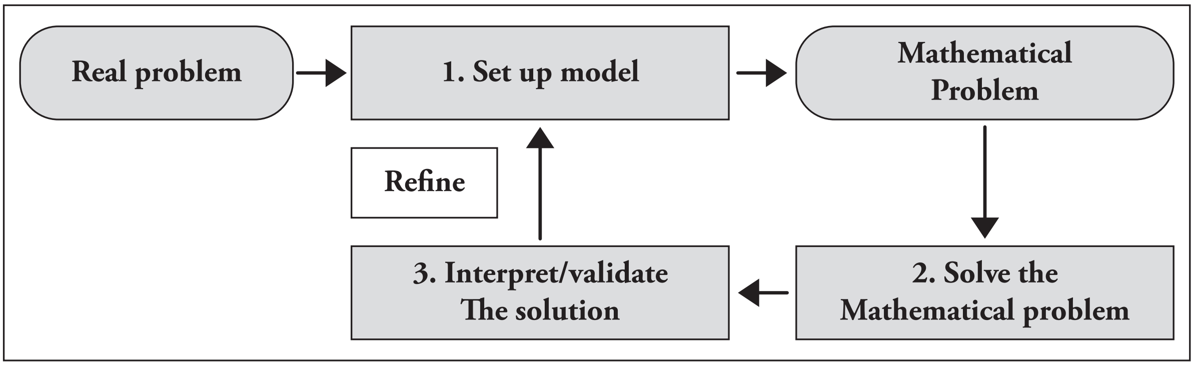



**Figure 9.1: Modelling and problem solving in mathematics, physics and engineering: The modelling and problem-solving cycle.**

The modelling and problem-solving cycle brings together three processes shown in Figure 9.1 (set up a model; solve the mathematical problem; and, interpret and validate the solution) and represents a coherent collection of skills expected of any graduate from the mathematical sciences. It is how these skills are applied as a whole and in a systematic manner that is of interest to us here and indeed that forms the very basis of modelling and problem solving. For example, the history of mathematical problem solving and investigations goes back to Polya's (1945) original work on heuristics (discussed in Chapter 8), and can exist independently of a mathematical modelling process. To explain what may appear to be a subtle difference, consider the example from Grove and Kyle (2014):

> *"…one of the most famous mathematical problems of all times is Fermat's Last Theorem which states that no three positive integers a, b, and c can satisfy the equation* $a^n + b^n = c^n$ *for any integer value of n greater than two. Fermat's Last Theorem is already expressed in mathematical terms, and so the modelling process can be omitted entirely. However, consider the problem that fascinated a 17-year-old Galileo: determine the period of oscillation of a bronze lamp suspended from the ceiling of the cathedral at Pisa. Before attempting a mathematical solution, an appropriate model for the oscillation of the lamp needs to be established, including assumptions, which can then be represented in mathematical terms."*
>
> Grove & Kyle (2014:129)

While a mathematician may engage with aspects of the modelling and problem-solving cycle, they will not necessarily follow each of the individual processes in a structured and coherent manner, as their starting point may be different. When they do, this forms what we define to be modelling and problem solving. To an extent, this definition may help us recognise a key difference between pure and applied mathematics: applying mathematics to a real-world problem requires the development of a model that seeks to describe the 'real-world'.

There are many ways in which one might model a particular real-world problem and each would result in a different mathematical problem. The mathematical problem (assuming it satisfies certain conditions) will usually have a unique solution or a well-defined set of solutions. In practice, numerical approximations to theoretical solutions may be needed. Then these solutions or approximations need to be interpreted within the original physical context. Often the outcome may be insufficient or inaccurate, most likely due to the assumptions that were made at the outset, and the modelling and problem-solving cycle needs to be repeated to build a mathematical description of the situation that is increasingly more realistic and representative of real-world behaviour.

Modelling and problem solving is therefore a collection of skills that need to be developed through experience. Getting started, once a real-world problem has been formulated, requires an ability to build a model of the real world that is relevant to the problem being investigated. This is the core modelling skill since without it the real problem is not converted into a mathematical problem and the investigation grinds to a halt. In the next section we present evidence which indicates that students' ability to solve physical problems in secondary education has declined substantially over the past 20 years.

## Background: The cause for concern

A detailed understanding of exactly what constitutes or contributes to what has come to be known as 'The Mathematics Problem' is relatively recent. In 1995, the London Mathematical Society led the production of a report, *Tackling the Mathematics Problem* (LMS, 1995), that made one of the first attempts to do this. It noted three areas for concern:

> *"The serious problems perceived by those in higher education are:*
>
> *i) a serious lack of essential technical facility—the ability to undertake numerical and algebraic calculation with fluency and accuracy;*
>
> *ii) a marked decline in analytical powers when faced with simple problems requiring more than one step;*
>
> *iii) a changed perception of what mathematics is – in particular of the essential place within it of precision and proof."*
>
> LMS (1995:3)

A subsequent report, *Measuring the Mathematics Problem* (Savage & Hawkes, 2000) identified the existence of a Mathematics Problem within the disciplines of mathematics, engineering and physics, and highlighted two contributing factors in particular: *"insufficient candidates with satisfactory A-level Mathematics grades for the number of degree places available"* and *"the freedom of A-level students to choose Statistics as an alternative to Mechanics"*.

Since 2000 we have seen a substantial increase in the number of students studying mathematics at A-level, and in the percentage of those awarded the highest grades (Grove, 2012). From the growth in both A-levels and university courses (see, for example Chapter 4) within mathematics and disciplines that contain a significant mathematical component it is thus evident that there are now more learners who have higher pre-entry qualifications in mathematics than previously. Despite this, the mathematics problem persists. The Institute of Physics report *Mind the Gap: Mathematics and the Transition from A-levels to Physics and Engineering Degrees* (IoP, 2011) indicates that many physics and engineering academics still feel that new undergraduates are underprepared as they commence their university studies due to a lack of fluency in mathematics.

*Measuring the Mathematics Problem* recommended that *"Prompt and effective support should be available to students whose mathematical background is found wanting"* (Savage & Hawkes, 2000), and while it is evident that the mathematics problem persists, progress has been made. An ample supply of free, good quality resources is available to help any students serious about remedying their shortcomings, and to help academic and support staff who aspire to assist students struggling at the school-university interface. In addition, a significant proportion of universities has invested in the provision of support mechanisms (see Chapter 4).

It can be argued that there are now several facets to the mathematics problem within higher education, one of which is: *"A lack of fluency in applying mathematics and specifically an inability to model and solve (unfamiliar) problems"* (Grove, 2012). This aligns with our experience of teaching first-year mathematics and physics students at two research intensive UK universities. An important issue appears to us to be an inability to apply mathematics as well as an inability to undertake the 'routine processing' of calculations. In particular, students struggle to identify the techniques and approaches required to solve problems. This should not, however, be taken to indicate that issues do not exist with students' core knowledge in these disciplines, but merely that the mathematics issues we are facing within higher education are evolving and may require different approaches to their solution.

The Institute of Physics report (IoP, 2011) found that many of the academics surveyed believed that mathematics and physics provision at A-level leads to students learning by rote rather than developing conceptual understanding. The report *Newton's Mechanics – Who Needs It?* (Savage & Stripp, 2009) highlighted similar concerns.

While this Chapter is perhaps not the place to dwell upon why such a problem exists, the fact that there is compelling evidence that the essential skills of modelling and problem solving are lacking amongst new undergraduates in mathematics, engineering and physics, implies it must be in some way linked to the pre-university curriculum and has been noted by the Institute of Physics:

> *"…changes in the nature of mathematics courses at school level have led to students being less proficient and confident in the mathematical skills required by physics degree courses"*
> IoP (2001:5)

Mathematics is an A-level subject where there have been numerous significant changes over the last fifty years, with more taking effect, or currently being planned. The nature of these changes are discussed extensively elsewhere (Smith, 2004; Gordon, 2005; Savage & Stripp, 2009:10; Lee & Dudzic, 2014), but a key feature has been a reduction in the opportunities that exist within A-level for students to apply their mathematical knowledge to solve problems. Perhaps the most drastic changes took place after 'Curriculum 2000' (Abramsky, Porkess, McColl & Sangwin, 2001) which ultimately led to a sharp decline in the number of students studying A-level Mathematics (Royal Society, 2008:63). As a consequence, revisions were introduced to both A- and AS-Level Mathematics qualifications for first teaching in 2004 (Porkess, 2003) in an attempt to address the issues that had been introduced and represented *"a serious attempt to raise the numbers taking mathematics in sixth form to previous levels"* (Porkess, 2003:13).

A key feature of the A-level changes introduced for 2004 was changing the balance between pure and applied mathematics: *"At present A Level Mathematics consists of 6 units; usually 3 of these units are pure and 3 applied. In the new scheme it will still consist of 6* *units, but 4 of them will be pure and 2 applied"* (Porkess, 2003:13). A consequence is that students are now typically studying less mechanics prior to university entry, particularly if they do not study A-level Further Mathematics, and this has observed implications when they enter higher education:

> *"Currently 30-40% of schools and colleges enter their students for at most one unit of mechanics. As a result, many students arrive at university to study physics, engineering and mathematics having studied at most one unit of mechanics. The reduction in the amount of Newtonian mechanics studied by many students as part of A-level Mathematics has resulted in a decline in students' modelling and problem solving skills"*
>
> Savage & Stripp (2009:17)

It is not only changes to A-level Mathematics that have contributed to this problem, there have been changes to other A-level subjects including Physics. A-level Physics and Mathematics are subjects that many students study in combination. For example, for examinations taken in 2011, almost a third of those studying A-level Mathematics also studied A-level Physics, and just over 80% of those studying A-level Physics also studied A-level Mathematics (Gill, 2012). By studying A-level Physics in conjunction with Mathematics, students had the opportunity to reinforce and apply their mathematical skills by tackling problems in physics. However, in recent times the requirement that A-level subjects be independent of each other has led to a reduction in the mathematical content of Physics A-level.

In the late 1990s, the Department of Physics at the University of Liverpool set about exploring the apparent paradox *"that incoming undergraduates have better qualifications but seem to know less than previous years"* (Milstead, 2002). They analysed the changing mathematical content of A-level Physics noting:

> *"A-level papers of one of the largest exam boards were selected. These dated from 1983 to the present day. The most striking fact was the purging of maths. The average number of mathematical steps needed to answer a question was constant at about four until the early 1990s. Two mathematical steps are typically needed now."*
>
> (Milstead, 2002)

They explored the change in difficulty of the, at the time, revised Physics A-level, by setting their undergraduate students in-class tests:

> *"Older (pre 1992) and more recent (post 1997) questions were selected. Both sets of questions covered the same topics and required the same basic knowledge. Scores were on average 1.6 times higher for the recent questions.*
>
> *We also repeated the exercise with second year students. As expected, they performed much better overall, although even they managed the older questions less well. It is hard not to conclude that the questions are not as difficult as they used to be."*
>
> (Milstead, 2002)

In 2011, attempts were made to tackle the inability of undergraduates to model and solve problems by a collaborative project through the National HE STEM Programme involving thirteen chemistry, engineering, mathematics and physics departments from eight UK universities. While each department adopted a slightly different approach, the underpinning philosophy throughout was to address the inability of incoming undergraduates to apply mathematical techniques to unfamiliar exercises, problems or situations. The interventions implemented during the first year of university study focused upon enabling students to model situations, solve problems, and have opportunities to engage with the application of mathematics in a variety of contexts.

## Mathematical modelling and problem solving at the University of Leeds

A new skills module, 'Mathematical Modelling and Problem Solving' (MMPS), was introduced into the first year of the undergraduate physics course in 2011/12. The aim was to enable students to understand the key role that mathematical modelling plays in the investigation and solution of physical problems – by developing two specific modelling skills through practice and reflection. The ability to 'set up a model of the real world' is the core modelling skill; its function is to transform a physical problem into a mathematical problem. Mastering this skill is an essential prerequisite for developing a second, more advanced skill – the ability to perform a full mathematical investigation by means of a multi-stage modelling and problem-solving cycle. In its present form, following a pilot in 2011/12, this new MMPS module has been offered as an elective to first-year physicists in 2012/13 and again in 2013/14 with uptake amongst the student cohort rising from 14 to 40 students.

The underpinning philosophy is to use a four-step strategy to develop students' core modelling ability. From the outset students are presented with, and challenged by, a wide range of problems in Newtonian mechanics designed so they can practice and develop their skill in setting up a relevant model of the real world prior to solving a mathematical problem. This process of converting a real physical problem into a mathematical problem is called 'modelling' or 'modelling the real world' and it has a simple structure consisting of 4 distinct steps that can be remembered by the acronym ADVaL:

1. **A**ssumptions: List the assumptions relevant to the problem.
2. **D**iagram: A diagram is constructed taking account of the assumptions.
3. **V**ariables: Variables are introduced onto the diagram.
4. **L**aw/principle: The application of a law or governing principle will give rise to equation(s).

### Module structure

A set of preparatory notes were sent out to students advising them to prepare for the module by becoming aware of 1) its aims and objectives; 2) the module structure; and, 3) key concepts/questions such as 'what is a model?', 'what is modelling?', and 'what has modelling got to do with problem solving?'. This provided a suitable focus for questions and discussion at the start of the first meeting as students were keen to understand the module structure.

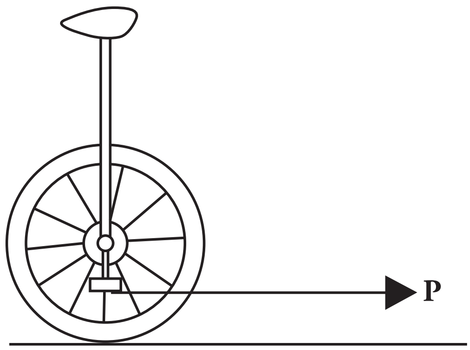
The module itself was split into two parts with *Preparation* (weeks 1 – 5) followed by two *Investigations* (weeks 6 – 11). An initial five-week period of preparation was necessary to allow students to address a variety of physical problems, individually and in small groups, with sufficient time to practise and develop a core modelling skill – the ability 'to set up a model of the real world'. Experience shows that such preparation is essential in order to not only master this core skill but also to understand its significance in *transforming the physical problem into a mathematical problem*. Following the period of preparation, students were then in a position to undertake two mathematical investigations – by following the various stages of the modelling diagram (Figure 9.1) and in each case writing an individual report for assessment.

**Preparation**

The primary aim of the first meeting with the students was to get them actively engaged with a number of interesting and challenging problems drawn mainly from Newtonian mechanics. A set of problems were introduced on the basis that they would provoke thought, generate discussion and identify misconceptions. 'Pulling a unicycle' is a classical problem with which students can get actively involved right from the start.

***Example: The unicycle problem***

A string is attached to the lower pedal of a unicycle. With a colleague or student pressing a hand on the saddle so that the unicycle remains upright, a string that is then attached to the lower pedal and a force P applied. In which direction does the unicycle begin to move?




To students beginning an undergraduate mathematical sciences or physics degree this will be a genuine problem (see Chapter 8). It is worth allowing students to think about and discuss what will happen. This can be followed with a demonstration, which in itself generates great surprise from most of those who have not seen it before, and then provides an opportunity to discuss what has happened by exploring the key conceptual issues.

**Setting up a model: A simple strategy**

The primary aim of the second teaching session was for the students to discover for themselves a strategy for setting up a model of the real world by tackling a simple modelling problem such as 'lunar exploration'.

***Example: The lunar exploration problem***

Imagine you are a scientist involved with a lunar exploration programme that requires the building of a track or pipe that circumscribes the moon. One member of the team identifies the need to raise the track 3 metres above the lunar surface – how much extra length of track would be needed for such an approach?

The focus here is not upon determining a correct solution, but how students make an attempt at obtaining a solution. This leads nicely into introducing the ADVaL strategy which can then be applied to increasingly more sophisticated problems: For example, reviewing experimental laws often used in mechanics such as 1) Hooke's law and the related concept of a light and inextensible string and 2) the law of static friction and the related concepts of a smooth pulley and the angle of friction.

**Modelling and problem solving in mechanics**

The aim of this five-week period of preparation was to give students plenty of practice in tackling unseen problems in mechanics. For each problem they used the ADVaL strategy to set up a model of the real world and then find a solution to the resulting mathematical problem. On this basis a modus operandi emerged for how the sessions were to operate and be delivered. Each week, the workshops began with students being given an unseen problem and invited to work with a partner so as to interact/discuss the setting up of a model and finding a solution to the mathematical problem. During this time the tutors, consisting of a mix of academic staff and postgraduate students, circulated, ready and willing to respond to student questions and queries. The final 15 minutes of each teaching session were left for tutors to go through the modelling and analysis with the whole group – inviting questions and drawing attention to key points/subtleties and any potential pitfalls.

The second workshop followed a similar pattern and concluded with students being handed an assignment consisting of two unseen problems to be worked on individually and submitted the following week.

**Taking stock: student feedback (after five weeks)**

When faced with a previously unseen problem, students soon come to realise that 'setting up a model' of the real world is the link which transforms the physical problem into a mathematical problem and then, and only then, is one ready to do mathematics and find a solution. Students come to see 'tackling a physical problem' as a 2-stage process, and as one student noted:

> *"You can't hope to solve these problems unless you can model."*

After five weeks of initial activities, student feedback was collected from the 2013/14 cohort. Almost all the students reported they had developed the confidence and ability to address unseen problems and there were signs that they were starting to enjoy the problem-solving experience. Since 2013/14 was the first time that a large group had elected to study this module, student comments were invited on all aspects of the delivery they had experienced: from practical demonstrations to workshops, worksheets, and the ADVaL strategy:

***Demonstrations:*** *"These are highly valued – They work well"*

*"Please ensure that this part of the teaching is not overlooked as it really helps to consolidate knowledge and initial ideas"*

***Workshops:*** *"I do enjoy the workshop style of teaching"*

*"A relaxed atmosphere with groups of students working together is good"*

***Worksheets (ADVaL):*** *"These are interesting and very helpful – The questions are stimulating and varied"*

*"Going into such depth with each problem was enjoyable"*

*"The ADVAL strategy is a new concept that helps to cement the ideas for modelling – It has changed the way I think about problems"*

***Module (so far):*** *"I feel that I have learned a lot in the first five weeks"*

*"I gained much confidence and insight from doing the worksheets"*

**Mathematical investigations**

By the start of week 5, the students had addressed a range of previously unseen physical problems by building, in each case, a suitable model, deriving a mathematical solution and, where possible, interpreting the results. They were therefore ready to be introduced to the idea of a more open-ended investigation tackled by means of the multi-stage modelling and problem-solving cycle (Figure 9.1). This was undertaken through small groups of three or four students.

The key feature was a much greater emphasis on interpreting and validating the solution. This was achieved by considering how their developed model aligned with observation, experiment or published data/evidence. After progressing once around the modelling and problem-solving cycle, students were encouraged to reflect on the strengths and weaknesses of their basic model and identify significant disparities between theoretical prediction and experimental or observational data. This then provided the motivation for them to set up a more refined model and continue as before.

Whereas the problems tackled over the previous five weeks of the module were, in some senses well defined, the investigations were much more vague and open to interpretation. The investigation 'brief' broadly defined an area for students to explore and so there were potentially many routes by which students could do this, or ways in which they might refine and extend the task. Students were offered the opportunity of identifying their own area for investigation which could then be developed in conjunction with the tutors.

***Example investigation:*** Imagine you are members of the Red Bull team of scientists and engineers responsible for overseeing Felix Baumgartner's world record skydive from 39km above the Earth. You have been assigned to investigate the dynamics of his motion from the stratosphere. In particular you need to predict his speed both as a function of time and distance fallen.

On the face of it, this may appear to be a trivial problem involving freefall under gravity. However, while this may be the starting point for a simple model, it is a great example of how a problem can be refined and developed through the modelling and problem-solving cycle. Students quickly realised that the problem is more complicated. For example, while the assumption that air resistance is negligible will hold outside of the Earth's atmosphere, this will no longer be true as Baumgartner enters the atmosphere. This introduces the concept that his acceleration can no longer be regarded as a constant and introduces the idea of terminal velocity. Further, the density of the atmosphere varies with height from the Earth's surface, and so this means that air resistance once inside the atmosphere will vary as a function of position (height). The organisers of the record attempt have made a range of data available for individuals to utilise (Red Bull, 2012) including NASA data giving the variation of density of the Earth's atmosphere with altitude, all of which was used by students to refine their mathematical models.

For their investigations students were instructed to adopt a specified structure when writing their project reports. This helped to introduce them to the idea of scientific writing. Their reports should begin with an abstract specifying clearly the problem(s) investigated and outlining *'what they set out to do'*, *'what they discovered'* and *'their conclusions'*. Their reports needed to provide a systematic account of the models investigated – from the basic to the most refined – in each case following the stages of the multi-stage modelling diagram (Figure 9.1).

**End of module student feedback and results: 2013/14**

A total of 38 students completed the module; all passed, with 27 awarded firsts and 6 achieving 2(i) classifications. While this is clearly positive, of most significance were the student comments which indicated they had appreciated the methods of learning that they had experienced, particularly through the investigations:

> *"I enjoyed the investigations; they made me think about problems in a more realistic way."*
>
> *"Sometimes it's unclear what the tasks are – what to do next! However, i* [sic] *appreciate its more about developing a new way of thinking."*
>
> *"I have learned new skills for applying maths to real world problems!"*

For the 2011/12 cohort, when this module was first introduced in its pilot form through the National HE STEM Programme, a parallel educational research study was undertaken to explore the impact of the approaches to helping students develop their modelling and problem-solving skills. This analysis (Pampaka & Williams, 2012) concluded:

> *"The course managed to re-introduce Mathematical Modelling & Problem Solving (MM&PS) into the undergraduate student experience in an arguably 'authentic' course in mechanics in first year Physics…Students' dispositions (and probably their awareness) of Mathematical Modelling significantly increased between measures 'before' and 'after' the course...The best students certainly revealed in their work a convincing grasp of modelling, the modelling cycle and model-refinement…"*
>
> Pampaka & Williams (2012)

## Concluding comments

This chapter has highlighted a particular aspect of The Mathematics Problem facing students as they make the transition to studying the mathematical sciences, and indeed other science, technology, engineering and mathematics subjects, within higher education. Students can arrive at university either unprepared, or lacking confidence, in being able to model physical situations and tackling less well defined problems. This can have implications for progression through their undergraduate programmes (see Chapter 13), and for their transition into the workplace where modelling and problem solving are skills expected by employers of STEM graduates.

Through a large-scale National HE STEM Programme, a number of universities became involved in tackling this issue and from this work we have presented one example of how higher education institutions are tackling this 'modelling and problem solving' issue. The example is provided as an attempt to provoke thought and debate as to how other universities might recognise and address this problem facing their undergraduate mathematical sciences students.

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# A17. Enquiry into Learning and Teaching in Mathematics and Engineering

**Grove, M.J.** & Kyle, J. (2014). Enquiry into Learning and Teaching in Mathematics and Engineering. In Cleaver, E., Lintern, M., McLinden, M. (Eds.), *Teaching and Learning in Higher Education: Disciplinary Approaches to Educational Enquiry* (pp.126-145). London, UK: SAGE.

# A18. Developing and embedding inclusive policy and practice within the University of Birmingham

McLinden, M.T., **Grove, M.J.**, Green, J.R. & Birch, A. (2014). Developing and embedding inclusive policy and practice within the University of Birmingham. *Education in Practice*, 1(1), pp. 18-21.

Paper

# Developing and Embedding Inclusive Policy and Practice within the University of Birmingham

**Michael McLinden[1], Michael Grove[2], Jon Green[3] & Andy Birch[4]**
[1] School of Education, University of Birmingham
[2] College of Engineering & Physical Sciences, University of Birmingham
[3] Deputy Pro-Vice Chancellor (Education), University of Birmingham
[4] Visiting Lecturer, Centre for Learning and Academic Development, University of Birmingham

**Abstract**
The University of Birmingham established an *'Inclusive Curriculum Working Group'* in February 2014 to explore how inclusivity can become more effectively developed and embedded within the curriculum in order to support colleagues in thinking about inclusive curriculum design so as to promote success amongst all students. The main focus of the Working Group is to identify challenges and barriers in order to provide practical solutions and embedded changes to policy and practice. This article describes the innovative data collection methods that will be drawn upon through a process of educational enquiry to monitor change over a given timeframe in relation to agreed goals and success criteria. This includes an organisational change framework (McKinsey 7S) that will be used to enable the impact of the Working Group to be measured and monitored over a given timeframe in relation to agreed goals and success criteria. Future publications will report on progress in relation to the proposed activities, evaluate the methodology and data collection methods and explore the extent to which the project outcomes can be drawn upon more broadly within the higher education sector.

## Introduction

As reflected in its Equality and Diversity Scheme (UoB, 2011), the University of Birmingham has a commitment to developing and promoting equality and diversity for all staff and students. As part of this commitment, and building on recent work in the higher education sector (for example May & Bridger, 2010; QAA, 2012), an *'Inclusive Curriculum Working Group'* was established in February 2014 to explore how inclusivity, in its widest possible sense, can be more effectively developed and embedded within the curriculum in order to support colleagues in thinking about *'inclusive curriculum design from a generic as well as subject or disciplinary perspective'* (Morgan & Houghton, 2011:5) so as to promote success amongst all students.

Inclusive curriculum design is described by the Higher Education Academy as an approach that *'takes into account students' educational, cultural and social background and experience as well as the presence of any physical or sensory impairment and their mental well-being. It enables higher education institutions (HEI) to embed quality enhancement processes that ensure an anticipatory response to equality in learning and teaching.'* (Morgan & Houghton, 2011:5).

To reflect this broad perspective, membership of the Working Group has therefore been drawn from across the University. It includes representation from the Guild of Students' sabbatical and non-sabbatical Officers who have activity portfolios in key inclusivity areas including mature and part-time students and female students. The main remit of the Group is to identify issues, challenges and barriers to greater inclusive practice, provide practical solutions to identified issues, and embed changes to teaching and learning approaches. In seeking to develop and embed such practice, the initial activities of the Working Group include:

1. Collating and disseminating resources and materials related to inclusivity.
2. Identifying and disseminating examples of effective practice in inclusive curricula.
3. Enabling wider representation and input, in particular from students, to help better understand and address inclusivity issues and needs.
4. Exploring how inclusivity may be better, and more naturally, embedded with core areas of University activity including, but not limited to:
    a. Resources and using technology and Canvas to create accessible learning materials
    b. Teaching delivery
    c. Assessment and feedback
    d. Personal tutoring
    e. Student access.
5. Organising events to raise awareness of good practice in inclusivity and share effective approaches from both within and outside of the University.

The focus and remit of the Working Group demonstrates the commitment of the University towards the description on 'equality, diversity and equality of opportunity' within guidance provided by the Quality Assurance Agency (QAA) on learning and teaching which notes:

*'An inclusive environment for learning anticipates the varied requirements of learners, for example because of a declared disability, specific cultural background, location, or age, and aims to ensure that all students have equal access to educational opportunities.'* (QAA, 2012:4)

By drawing upon both University and national policy documents in respect of diversity and inclusion, a series of draft principles have been developed that will serve to guide the activities of the Inclusive Curriculum Working Group (see Box 1).

1. Whilst the nature of students' particular learning experiences may vary according to location of study, mode of study, or academic subject, as well as whether they have any protected characteristics, every student should experience parity in the quality of learning opportunities.
2. Equality of opportunity involves enabling access for students who have differing individual requirements as well as eliminating arbitrary and unnecessary barriers to learning.
3. Disabled students and non-disabled students should be offered learning opportunities that are equally accessible to them, by means of inclusive design wherever possible and by means of reasonable individual adjustments wherever necessary.
4. Offering an equal opportunity to learn is distinguished from offering an equal chance of success.

Box 1: Draft principles guiding the Inclusive Curriculum Working Group (adapted from QAA, 2012; QAA, 2013).

## Research design

The role and function of the Inclusive Curriculum Working Group illustrates a strategic approach to enhancement that seeks to bring about desired change in policy and practice through working with a wide range of individuals from across the University. It provides a mechanism to ensure a coordinated and coherent approach at a practitioner level with the ability to engage students directly in the development and delivery of the activities undertaken.

However, in seeking to bring about such change, natural questions regarding how this change may be measured and benchmarked are raised in order that the extent of genuine progress can be determined. Whilst the more robust evaluation of educational activities is becoming increasingly widespread across the sector, this is often in relation to discrete or focused interventions; seeking to explore the progress of interventions and approaches that take place across a large organisation is far more complex, and in addition, further complicated by not only the need to measure changes in policy and practice, but also cultural and attitudinal shifts. This poses an interesting debate that can be explored through a process of educational enquiry in a manner that is reinforced by the disciplinary skills of those involved in the process and as described by Cleaver, Lintern and McLinden (2014).

Given the emphasis upon implementing institutional change at a number of levels and involving a wide range of stakeholders it is proposed that a cyclical process of 'action research for organisational change' will be drawn upon for the Inclusive Curriculum Working Group (Lynch, McLinden, Douglas & McCall, 2012; Zuber-Skerrit, 1996). This incorporates:

1. Strategic planning (Plan)
2. Implementing the plan (Action)
3. Observation, evaluation and self-evaluation (Observe/Monitor)
4. Critical and self-critical reflection on the results and making decisions for the next cycle of research (Reflect).

Initial meetings of the Working Group to date have been predominantly concerned with the 'planning' stage of this cycle. The activities have included determining the scope, remit and membership of the group; agreeing key terminology; identifying key resources and developing suitable methods for data gathering and monitoring institutional change. A recent programme of activity has sought to explore, by involving a wide range of staff and student stakeholders from across the entire University, current issues and challenges relating to inclusivity that can form the basis of a series of activities that the Working Group will oversee during 2014/15.

What constitutes success?

Before an approach to measuring or determining 'success' can be developed, it is necessary to first consider what success might look like and how it may manifest itself across the institution should the Working Group deliver on its identified mission. Such considerations firmly align with the planning stage of the Participatory Action Research Cycle. By having an appreciation of what successful outcomes from the Working Group could be, this makes it possible to identify approaches, including measures, that allow the progress towards these outcomes through a series of indicators to be measured. While not exhaustive, Table 1, provides some examples of success indicators/measures that can be applied to the Working Group:

| Indicative measures of success |
|---|
| A visible web presence related to inclusivity, including staff and student internal and external webpages |
| Availability of a range of resources from within the University that are accessed and utilised by both staff and students |
| Positive changes to International Student Barometer Data |
| Positive changes to Birmingham/National Student Survey Data |
| Student performance, and in particular a narrowing of the attainment gap amongst learners |
| A reduction in the number of appeals and complaints due to issues associated with inclusivity |
| Inclusivity explicitly embedded within the University Teaching and Learning Strategy |
| References to inclusivity with University appointments and staff selection and promotion |
| Inclusivity is firmly embedded within the values of the University |

Table 1: Indicative success measures: Inclusive Curriculum.

Monitoring change

A particular challenge when restructuring multi-level institutional procedures is how to ensure alignment in relation to proposed changes. Given the broad remit of the Working Group, particular methods are required to enable its impact within the institution to be measured and monitored over a given timeframe in relation to agreed goals/success criteria. One model that has been outlined as being applicable to help organisations seek 'harmony' in their activities in order to create more inclusive practice within higher education is the *'McKinsey 7S Framework'* (May & Bridger, 2010). The framework is based upon seven interdependent elements that contribute to organisational effectiveness (Figure 1). The seven elements are further broken down into 'hard' (strategy, structure and systems) and 'soft' elements (shared values, skills, style and staff). The authors of the model argue that for an organisation to perform effectively there needs to be alignment and coherence between each of seven elements (Pascale & Athos, 1981). The model also offers the opportunity to gauge the effectiveness of any change made within a particular 'S' in relation to the other elements by considering the various inter-relationships and the impacts it may have upon those.

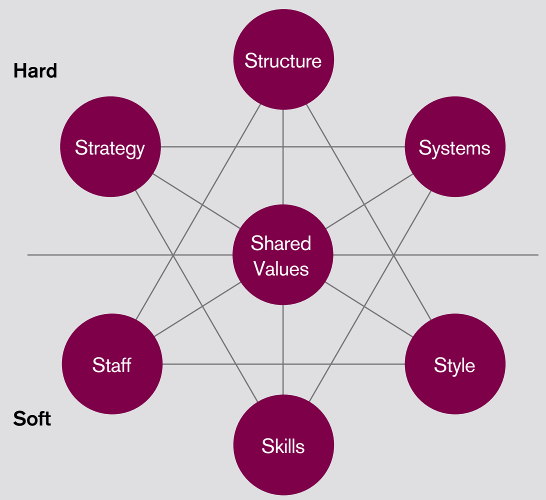


Figure 1: The McKinsey 7S Framework.

The McKinsey 7S Framework highlights the fact that, in creating whole organisational change, attention must be paid to different elements of the organisation and is based on the premise that, for an organisation to perform well, each of the seven elements needs to be aligned and mutually reinforcing. For an organisation to perform 'effectively' therefore, there needs to be alignment and coherence between each of the elements. As such the model can be used to help identify what needs to be realigned to improve performance during change. The model could therefore help to demonstrate the inter-relationships between the factors that together support institutional effectiveness and show how changes in one area can have knock-on effects for other areas demonstrating the need for any proposed change to be looked at in relation to the whole (Peters & Waterman, 2004).

Given the Working Group is seeking to bring about changed institutional practice in relation to an inclusive curriculum this framework will be drawn upon to explore different elements of the organisation at various points in the action research cycle to help demonstrate the inter-relationships between the factors that together support institutional effectiveness and show how changes in one area can have knock-on effects for other areas. The framework can be used therefore as an initial audit tool within the planning stage of this cycle and as a means of identifying and reviewing progress towards agreed priorities within later stages. A series of pilot 'measures' are being developed in relation to different sources of evidence and will be used as a means of monitoring change over the selected timeframe. Examples of indicative evidence sources and measures in relation to each element of the framework are presented in Table 2.

| 'S' | Indicative Evidence Source | Indicative Measures |
|---|---|---|
| Strategy | University strategy and policies, for example:<br>▪ Shaping our Future (Birmingham 2015)<br>▪ University Education Strategy<br>▪ The Student Charter<br>▪ Equality Scheme (2011-2015) | Reference to key words relating to project focus |
| Structure | Organisational structures, for example:<br>▪ University structures<br>▪ College and School level structures | Measures of gender, ethnicity |
| | Campus or 'hard' structures, For example:<br>▪ Buildings<br>▪ Campus<br>▪ Teaching rooms | Measures of type, access, hearing assistance, lecture capture, wheelchair accessibility, etc. |
| Systems | General access systems, for example:<br>▪ Internet<br>▪ Intranet | Measures of language and accessibility (for example number of clicks to reach inclusivity issues) for relevant pages |
| | Student or staff based systems, for example:<br>▪ VLE<br>▪ Lecture capture | Measures of language and accessibility;<br>usage statistics (amount, specific needs groups, for example dyslexia or non-English speaking background) |
| | HR or Admin Systems, for example:<br>▪ Promotion systems<br>▪ Athena Swan | Measures drawn from metrics: percentage change in gender and ethnicity in promotion to senior grades |
| Staff | Reported demographics, for example:<br>▪ Gender<br>▪ Ethnicity<br>▪ Other relevant measures drawn from human resources reporting systems | Measures as a percentage change |
| Skills | Human capital measures, for example:<br>▪ Online diversity course<br>▪ Staff qualifications<br>▪ Other measures of skills base | The UK Professional Standards Framework for Teaching and Supporting Learning in Higher Education includes specific links to inclusivity and access, and percentage of staff who subscribe to those links through fellowship of the Higher Education Academy |
| Style | Current attitudinal measures, for example:<br>▪ Staff survey<br>▪ Leaving interview data<br>▪ Complaints statistics (inclusivity related) | Measures of percentage change; equality and diversity, bullying and reporting processes |
| Shared Values | Espoused values | Relevant strategies policies and statements |
| | Derived values | Explore extent to which there is alignment between espoused values and those derived from analysis |

Table 2: Indicative evidence sources and measures in relation to the McKinsey 7S Framework.

As no literature has yet been found reporting on how the McKinsey 7S framework has been applied in the context of higher education, part of the work of this project will be to develop the model for use within the University. This may then have broader strategic value to other change-oriented initiatives both within the University and the higher education sector more broadly.

### Conclusion

The design and remit of the Inclusive Curriculum Working Group aligns with findings by the Higher Education Academy about the need for inclusive learning initiatives to take a multi-pronged approach, be systematic and holistic, take an embedded approach, and target multiple institutional functions (Thomas & May, 2010). By framing the activities of the group within a process of educational enquiry, opportunities are presented to develop and test innovative data collection methods such as the McKinsey 7S that traditionally may not have been used within higher education settings in order to monitor change. Future publications are planned to report on progress in relation to future activities within this project and evaluate the selected methodology and data collection methods.

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# A19. Sustainability of Programme Outcomes

**Grove, M.J** (2013a). 'Sustainability of Programme Outcomes' in Grove, M.J. *National HE STEM Programme – Final Report.* Birmingham, UK: University of Birmingham, pp. 177-212. ISBN 978-1-909557-01-7. Available at https://www.birmingham.ac.uk/Documents/college-eps/college/stem/national-he-stem-programme-final-report.pdf

# Section 8:
# Sustainability of Programme Outcomes

**Introduction**

1. Within its March 2009 proposal to the Funding Councils, the National HE STEM Programme set itself a challenging series of objectives (Box 2.1). A key feature of these objectives, both explicit and embedded, was that the activities undertaken by the Programme should be sustainable within the higher education sector in the longer-term. Not only this, the Programme has sought to embed a longer-term way of working by encouraging sustainable collaborations and acting as a catalyst for change within higher education institutions.

2. This section seeks to explore the potential for the longer-term sustainability of the activities that the Programme has sought to embed within the higher education sector, and it builds upon the approach and methodology used for the Programme's Internal Sustainability Review which was compiled in September 2011 for submission to the Funding Councils. The evidence utilised within this section has been captured from a range of sources, but a key source is from the case studies and reports produced by each project lead describing their work within the Programme.

3. For the purposes of this discussion, it will be necessary to differentiate between 'sustainability' and 'legacy', particularly as the legacy of the Programme forms a section (Section 9) of this report. However, a natural overlap between the two is to be reasonably expected as their boundaries are often somewhat blurred. In addition, while the CFE External Evaluation considers sustainability at four levels (policy, sector, institutional, and activity/practice), the analysis that follows focuses primarily upon 'institutional' and 'activity/practice' levels. Consideration is however given to sustainability at a 'sector' level in terms of the extent to which developed networks and communities of practice might be sustained post Programme.

4. The previous sections of this report have explored the work of the Programme across its three strands, and as such have explored the impact and sustainability of these activities and practices within the higher education sector. In this section, the focus is upon an overarching look at sustainability within the context of the work of the entire Programme.

**Sustainability vs Legacy**

5. 'Sustainability' is a term that is used with a variety of meanings and for a variety of different purposes. For the purpose of this report, it is necessary to adopt a consistent definition, and within the context of the National HE STEM Programme, the sustainability of an activity is deemed to be

realised when: it will continue, in current or modified form, within at least the higher education institution(s) initially involved in its development and implementation, after National HE STEM Programme support ends.

6. Such a definition was utilised as the basis for the Internal Sustainability Review, however in that instance caution was needed as it required an activity to already be complete in order that it no longer required Programme support. When the Internal Sustainability Review was undertaken in September 2011, it was the case that the majority of Programme activities remained ongoing at the time, and so a variation upon this definition was applied which focused upon definite plans for sustainability by those undertaking or supporting the work. By this, it was meant that the individuals and HEIs involved made a clear and explicit statement of their plan to continue the activity post Programme and provided details of what that approach would be.

7. With the Programme concluding its formal activities on the 31 July 2012, it is now the case that all Programme supported activities have concluded, but this in itself does not make it any easier to make quantifiable and objective assessments on the sustainability of Programme Outcomes. This was noted within the Programme's External Evaluation:

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**"Robustly measuring sustainability is though inherently difficult when a Programme was only just drawing to a close. It is only when the external support has been fully removed for six to twelve months (or potentially even longer) that sustainability can be conclusively demonstrated." CFE, Summative Evaluation of the National HE STEM Programme (2013)**

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8. While an activity may appear to be continuing, it could equally be the case that its development is still continuing, albeit without the support of the Programme, or that insufficient evidence is currently available to make a judgement as to its overall effectiveness and as such whether it will remain a core future part of individual, departmental, faculty, or institutional provision. While the continuation of an activity immediately after the conclusion of a Programme is a significant positive, it is, at this stage, only an indicator of the longer-term sustainability that the Programme was seeking.

9. An activity needs to be continuing for a period of time in order to be judged sustainable, in either its original, or a modified form, and the three-year timeframe of the Programme makes this impossible to assess:

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**"...university programmes are reviewed in cycles (perhaps 3 years) with minor annual review of modules.....we are only now getting to grips with amending and supplementing resources, things like sustainability and continuation will depend in large part on how successful this initiative is seen to be in academic year 2011/12. We won't have exam results to compare with the current year until summer 2012. If they are really good we might have a chance of persuading some colleagues about adopting changes in 2012/13."**
**[Academic Member of Staff, HE Curriculum Innovation and Enhancement Projects]**

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For an activity to be sustainable, it needs to offer some demonstrable, or perceived, benefit for those stakeholders involved. Such benefits might be identified in the longer-term through evaluation or research, but in the earlier stages could be indicated by the feelings or perceptions of staff, students and other stakeholders that the activity is offering some form of assessed benefit to the practices of a department, faculty or institution. Equally, activities might continue to be modified and adapted so that they exist longer-term in an almost unrecognisable form, or even exert a wider influence beyond what was originally intended that gives rise to more substantial change; here the activities will have a legacy, an influence that continues to live on, but which may be much harder to determine.

10. Given such challenges, another appropriate analysis is to explore longer-term potential for sustainability by considering a series of 'sustainability indicators' that were first introduced within the Internal Sustainability Review. The sustainability indicators give an indication of whether the environment in which the activity is taking place is conducive to it having a high likelihood of continuation beyond the end of the Programme? If so, these can then be used as a proxy measure to infer the overall likelihood of sustainability of the activity.

11. Sustainability and legacy are linked; if an activity is sustainable it naturally leaves behind, as a legacy, a new or enhanced practice that did not exist prior to the work of the Programme. Additionally, participating in the activities of the Programme might have led to wider influences with other aspects of the practices of an institution being enhanced or informed. The 'legacy' associated with the Programme's activities is therefore defined to be the influence that exposure to the work of the Programme has had amongst those who have participated in its activities. This definition not only includes any specific activities (projects) undertaken, but also where learning, resources, or collaborations have led to the development or enhancement of institutional provision, or a change upon the culture of an individual, department, faculty or institution:

**"…there has been a massive change in institutional attitude to those lecturers who have no research responsibility. In summer 2011, I was part of a review team that drew up new promotion criteria to allow such lecturers to be promoted to Professor without a research profile. The term Teaching Fellow was abandoned and everyone is now referred to as Lecturers." [Academic Member of Staff, University of Exeter]**

**"We have mainly achieved the goals of our project, and have outstripped them in many ways. Employability has become the driving force of much of what we do with our students, and without this project this would not have happened." [Project Report, Identifying Skill Gaps of Employers and Mathematics Undergraduates, University of Leicester]**

**"The effect on faculty staff has been interesting, resulting in a good deal of reflection on their approach to teaching and the establishment of a new research interest in engineering education." [Academic Member of Staff, Swansea Metropolitan University]**

12. While the legacy associated with those universities who have participated in the activities of the Programme will be explored within this section of the report, the legacy, with a particular emphasis upon continuation plans, of the six Spoke universities and four Professional Bodies who formed the Programme Team will be explored separately within Section 9.

**Still a Case of Too Early to Tell?**

13. The September 2011 Internal Sustainability Review asked the question whether, at the time, it was too early to make a reasonable, and meaningful judgement, as to the likelihood of an individual activity being sustainable. Of particular consideration was the fact that it was typically only smaller scale activities (less than £10,000) that by then had completed their work, and that the larger scale projects, operating primarily at departmental or faculty levels, remained very much active. It therefore seems pertinent to ask the same question again.

14. It is now the case that all supported activities of the Programme have completed, and as such Programme support has been removed. There also exists a much wider, and more independent evidence base upon which the Programme can draw. In addition to the individual case studies and project reports, there is evidence from the external evaluation of the Programme by CFE which independently surveyed 248 project leads in relation to their work, and semi-independent data collection and analysis of four strands of the Programme's activity to capture key learning. Furthermore, a number of projects have published the outcomes of their work in journals and other publications. All provide a much more robust evidence base upon which conclusions can be drawn, but with no guarantee:

**"The analysis of this evidence gives an indication of the likelihood that the Programme's outcomes will be sustained, but by no means guarantees that they will be sustained." CFE, Summative Evaluation of the National HE STEM Programme (2013)**

This is consistent with conclusions reached by the Programme's former external evaluators, West Midlands Enterprise, in their external September 2011 sustainability review:

**"…there are many reasons for expecting that widespread sustainability will be achieved at the project level, in terms of activities either continuing beyond the life of the programme itself, or giving rise to other activities that will carry the principles forward – though this certainly cannot be proved." West Midlands Enterprise, External Sustainability Review (2011)**

15. The CFE survey of project leads asked them to indicate the extent to which the work they had undertaken would be sustained beyond the end of the Programme:

**"Our results indicate that the majority of respondents will be continuing STEM-related activities in some form, and in many cases the level of activity undertaken during the Programme will be continued or increased. Almost all (93.6%) involved with curriculum development and enhancement, 88.6% of those involved with HE engagement with schools and colleges, and 87% of those involved in graduate skills development intend to continue their project activities in some way. Two-thirds (65%) of respondents involved in workforce development activities indicated that they would continue their project activities beyond the end of the funding period to the same or an increased extent." CFE, Summative Evaluation of the National HE STEM Programme (2013)**

Such findings are further reinforced by those obtained from semi-independent synthesis work undertaken across all three strands (Box 2.2) of Programme activity, and which explored a number of projects within each strand in detail.

**"…the stakeholders questioned were generally optimistic about the sustainability of what had been achieved by their projects on the grounds that: the greatest expense had been incurred in meeting the initial development costs; changes have been embedded into programmes of study and can now be sustained out of departmental teaching and learning funds…" Tolley et al., Investigating Longer-Term Curriculum Change and Institutional Impact within Higher Education (2013)**

**"…projects have indicated they will continue with the developments beyond the funding period."**

**"The projects have developed change within HEIs at an individual course, department or faculty level."**

**Kettle & Smith, Lessons Learned and Achievements from the Regional Action Plan and Legacy Projects (2013)**

16. There remains, however, a need for caution before drawing longer-term conclusions as a number of larger scale projects have yet to fully evaluate outcomes and demonstrate their effectiveness, or have some unexpected challenges to overcome:

**"The projects have in many cases provided pilots for new approaches to engaging employers, to changing curriculum or initiating new approaches in their discipline communities. They have generally not reached the stage of evaluating outcomes for students or measuring the effectiveness in enhancing the student learning experience." Kettle & Smith, Lessons Learned and Achievements from the Regional Action Plan and Legacy Projects (2013)**

**"The short course has now started and will continue until March 2013 so it is too early in the process to get any feedback from the employees or their employers." [Academic Member of Staff, University of Sunderland]**

17. Additionally, one of the last open calls within the Programme was the 'Practice Transfer Adoption Scheme' which enabled higher education institutions to adopt and embed practices developed through the Programme. Implementation of the activities within the adopting departments commenced in early 2012, and as such, despite the activities being based upon effective practices, not all adopting departments are in a position to judge how effective these activities will be for them or their students:

**"The Numbas server is deployed at Kingston…and its support and maintenance is guaranteed for 12 months. Beyond that timescale the School of Maths will resource its maintenance should the Numbas trial in academic year 2012/13 show the expected benefits to staff and students at Kingston." [Academic Member of Staff, PTA Adopter of NUMBAS, Kingston University]**

18. It therefore seems reasonable to conclude that the sustainability of the work established through the Programme looks positive, certainly at 'institutional' and 'activity/practice' levels, and particularly in the short and medium term. However, it still remains 'too early to tell' regarding longer-term sustainability prospects as these will only be evident some several years after the conclusion of the Programme.

**Early Completing Projects**

19. The Programme's Internal Sustainability Review included an associated annex which featured case studies of impact and sustainability of sixty Programme projects. Of these projects, 27 were marked as complete, and all projects indicated an approach to sustainability that would see their activities continue into the future. Using additional information project leads have subsequently provided to the Programme, their further engagement with the Programme to transfer and embed their practices more widely, or information gathered from a simple web based search, it has been possible to identify numerous examples of this work being continued, and in some instances, developed further.

20. Seven of the projects involved undertaking outreach activities initiated by the four pilot projects with a view to the universities involved incorporating them within their own practices. Many of these activities continue to be visibly offered as a part of departmental outreach provision. For example, the Mathematics at Work Day (University of Salford) ran again in June 2012[1], the Hampshire Mathematics Challenge (University of Southampton) was offered again in 2012 engaging 335 students[2], and the Pop Maths challenge (Manchester Metropolitan University) took place again in 2012 and is currently scheduled for March 2013[3]. At the University of Reading, activities derived from the Chemistry for our Future initiative form a core part of the departmental outreach offering[4].

[1] http://www.cse.salford.ac.uk/mathematics/taster-day.php

[2] http://www.southampton.ac.uk/maths/outreach/activities/hampshire_maths_challenge_2012.page

[3] http://www2.docm.mmu.ac.uk/STAFF/N.Rattenbury/PopMathsQuiz/

[4] http://www.reading.ac.uk/chemistry/outreach/chem-outreachindactivities.aspx

21. Eight of the completed projects resulted from one of the first open calls for projects that the Programme initiated (the Collaborative Projects Initiative). At the University of Nottingham, the pro-active interventions to facilitate transition for engineering students of non typical backgrounds not only continue, but they have been transferred to the University of Exeter. Similarly the Science Communication and the Media module developed by the University of Birmingham continues within both the School of Chemistry and the School of Biosciences, but has also been adopted by Queen Mary University of London and the University of Bradford.

22. Two projects focused upon computer based assessment, and eAssessment in mathematics and related disciplines continue to be a key feature at the Universities of Birmingham and Newcastle; further, their work was extended by an additional Programme project, and agreement has been reached through the Heads of Departments of Mathematical Sciences to maintain the community of practice that developed in this area. At Aberystwyth University, Gwydffan/Science Van continues to be a core part of physics based outreach, and the work at the University of the West of England to construct a coherent STEM strategy with schools saw a further five activity days take place with Bristol Schools in May/June 2012 engaging around 750 Year 8 pupils.

23. Other projects have contributed to an enhanced institutional approach. At Queen Mary and the University of Bath, the project leads of the STEM Communicator and Illusioneering projects, who were both also actively involved in the More Maths Grads Pilot project, actively contributed to their institutions securing support from Research Councils UK to establish Public Engagement with Research Catalysts[5]. Similarly at the University of Exeter, not only was the Outreach Community of Practice project extended, but it has resulted in an ongoing initiative now supported by the University of Bath[6]; additionally Exeter was also successful in securing a Public Engagement with Research Catalyst. While it cannot be claimed that the work undertaken by these institutions through the National HE STEM Programme resulted in the success of securing these Catalysts, it is known to be the case that the activities formed a component of their proposals:

**"The senior managers at Bath were sufficiently convinced by the project to include it within the institutional bid for catalyst funding." [Project Report, Embedding Accredited STEM Communicator Models, University of Bath]**

24. Further examples of continued activity are evident. A collaboration initiated between Queen Mary University London and the charity Generating Genius to support the progression into university of students from Afro-Caribbean backgrounds continues as evidenced by the commitment within their OFFA Access Agreement (see Table 8.1). At the University of Hull, the distance learning resources created for a foundation degree in the chemical sciences have now been extended to enable students to 'top-up' to BSc level via distance learning.

### Indicators of Sustainability: Recently Completed Projects

25. Within the many final reports produced at the conclusion of Programme activities, there is both a clear commitment, intent and plan for sustainability; the series of case studies included within Section 12 of this report, developed from final project reports, demonstrates this. Further, in many of the reports or information that was provided by project leads to the Programme after its conclusion on the 31 July 2012, there is clear evidence of the activities continuing in the 2012/13 academic year.

26. While it is natural to treat such statements made by those running the projects with caution, such individuals are often best positioned to identify the potential for sustainability, and are ideally

[5] http://www.rcuk.ac.uk/per/Pages/catalysts.aspx

[6] http://www.hestem-thirdsector.org.uk

placed to put appropriate plans in place. In addition, they can indicate another important factor, the commitment and belief of those running the projects which will typically translate to a natural desire and work ethic to ensure they succeed.

27. For projects that have only recently completed it is not possible to accurately assess whether they will be sustainable in the longer-term at this stage, however it is possible to identify factors that will contribute towards the longer-term sustainability potential of an activity which may then be used as an indicator, and these may themselves already demonstrate short-medium term sustainability. This might be further resource, or a determined commitment:

**"The sustainability of these activities will be supported by a new education engagement officer in the Faculty." [Project Report, Teacher Advisory Board, University of Leeds]**

**"We have to continue with this activity in some form. The project has enabled us to do more in a short timescale than we could otherwise have achieved…" [Project Report, A study of the key drivers in determining workforce engagement with HE level provision of training in the Aerospace Sector, University of the West of England]**

Such an approach was first implemented within the Internal Sustainability Review, and revisiting it here is not only advantageous in terms of exploring potential for longer-term sustainability, but it also enables some of the principles (Box 2.3) the Programme sought to embed within its work to also be further explored.

28. For the Internal Sustainability Review an analysis of a range of project proposals, interim reports, case studies and other documentation from National HE STEM projects and activities was undertaken. This enabled a series of ten factors, or 'sustainability indicators' to be identified. These 'sustainability indicators' are factors that, when present, are likely to contribute to an activity being sustainable in the longer term and may therefore be used to make a reasonable judgement relating to the sustainability of an activity. In compiling this final report, an increased range of project materials were reviewed and as such formed a significant sample of the Programme's overall work across all activity strands, funding streams, and partners. This further analysis indicates that not only do these ten factors remain valid, but when completed projects analysed within the Internal Sustainability Review were revisited, they appear to function as reasonable indicators of the sustainability potential of projects beyond the end of a funding period.

29. Not all ten indicators need to be present within a given activity in order for it to have potential for longer-term sustainability, indeed it may be only one or two, and even then if all ten are present there is no absolute certainty. However what they do demonstrate is that there is some effect or influence that is making a valid contribution, or has a potential to make a contribution, towards sustainability. The ten factors are shown in Box 8.1.

1. **Embedding the Importance of Sustainability at the Outset:** Ensuring that sustainability is seriously considered by project leads during the development stage of an idea and is subject to rigorous scrutiny. Then, ensuring sustainability is considered and questioned throughout the lifetime of an activity. This will enable approaches to sustainability to be embedded from the start, rather than at the end of a project when it may be too late.
2. **Alignment of Activity with Wider Priorities:** The activity aligns with a wider set of priorities, and as such form part of a 'broader' picture. This might be institutional or national priorities, and as such provides opportunities for leveraging additional support or commitment.
3. **Institutional Commitment:** Buy-in or support is provided by the institution. This may be additional financial resource for development, to ensure on-going delivery, or in-kind support, such as the allocation of additional staff time or incorporation of the activity within workload timetabling.
4. **Evaluation:** Evaluation is an important part of the education development process. A robust commitment to (internally) evaluate should be in place prior to the commencement of any project. Evaluation is not only important because it provides evidence of impact, but also because successfully demonstrating impact leads to recognition, institutional or personal, which subsequently contributes to a sense of identity and the potential for wider opportunities and working.
5. **Dissemination:** Work to disseminate indicates there is a story to 'tell', and an individual belief in the ideas and learning being shared. It demonstrates a personal commitment to the activities and ideas.
6. **Professional Development:** Many developmental activities include a level of professional development. This means there is either individual learning, learning amongst others engagers, or a concerted effort to transfer the knowledge and expertise to others through mentoring or training events. Professional development is an indicator of sustainability, maybe not of the original idea itself, but of the ability to apply the gained learning or skills in a wider context, and within other institutions and with an almost unlimited potential for impact across the duration of an academic career.

7. **Developing a Community Identity:** Bringing together like-minded individuals or those who wish to learn from each other, share ideas and practices, or supporting/overseeing the ongoing nature of activities within a community through a co-ordinating and networking function.
8. **Wider value:** This might be termed 'transferability': the potential of an activity to extend beyond its initial institution to be used by others within the sector. It has clear value potential/benefit to others.
9. **Up-Front Investment:** Many developmental activities require an initial 'up front' outlay. This may be to develop resources, purchase equipment, or to buy-out staff time to develop necessary frameworks. After this initial work, ongoing delivery costs will often be lower if consumables are not involved. The significant resource cost then is staff-time which, if there is perceived to be benefit to an institution, can be allocated to the ongoing continuation of an activity.
10. **Proven Starting Point:** This is similar to 'Up Front Investment' but the development work and learning has already been applied elsewhere, and the opportunity exists to build upon 'what works' and commence the activity from an advanced starting point based upon the knowledge and expertise. Resources may exist, and the value and impact of the activity will often be evident.

**Box 8.1: Sustainability Indicators within the National HE STEM Programme**

### Indicators of Sustainability Embedded within the Programme

30. The process of initiating change within higher education institutions is a longer-term investment, and its existence was unlikely to be fully demonstrated within the three-year timeframe of the Programme. Despite this, numerous examples of impact and legacy can be seen at a variety of levels, and there is significant evidence that the activities and practices established by the Programme will be sustainable. It is now appropriate to further explore the potential for sustainability of the large-scale activities that have only recently completed relative to the indicators in Box 8.1.

### Embedding the Importance of Sustainability at the Outset

31. The importance of sustainable activity has been embedded within the Programme from the outset. This has been specifically commented upon by both West Midlands Enterprise and CFE within their external evaluation reports:

> **"...our judgement is that both in terms of design, and in terms of implementation, sustainability is being taken very seriously across the programme." West Midlands Enterprise, External Sustainability Review (2011)**

> **"In implementing the Programme delivery model and commissioning projects/activities through the discipline strands, the regional spokes and the national hub, sustainability was a key selection criterion. There is evidence to suggest that projects/activities were rejected on the basis they offered limited potential for sustainability." CFE, Summative evaluation of the National HE STEM Programme (2013)**

32. All activity proposals were not only required to demonstrate a clear intent for sustainability, but also a plan for how this was to be realised. This approach meant that those activities which were never going to be sustainable, were not supported, and as such, this has undoubtedly led to a higher overall percentage of sustainable activities within the Programme. This is not to say that more innovative, untested, or perhaps even 'risky' ideas were rejected, but that even these needed to give careful thought as to what their longer-term future might look like if they were successful:

**"It involved taking a risk and trying something new and untested. Over the last two years we have adapted our provision in regard to student feedback and have had to make changes due to University and other constraints. This project has succeeded in ways that had not been foreseen and appears to have made a real difference to student engagement retention and achievement which demonstrates the value of trying speculative ideas."**
**[Project Report, Maths Arcade, University of Greenwich]**

**"A risk was taken by combining two disciplines that are often seen as disparate, and that risk has proved to be worthwhile." [Project Report, Connect to Science, University of York]**

**"…the partnership delivering the National Hydrographical Academy provided 'proof of concept' to the University of Plymouth which is now resourcing it for the future."**
**Haselgrove, Engagement and Collaboration in the National HE STEM Programme (2013)**


33. Progress towards sustainability was also monitored throughout. In particular within interim reporting, but also during networking meetings established in the final year of the Programme to bring activities together; this allowed approaches towards sustainability to be shared. A particular template used by the South West Spoke to encourage projects to reflect upon sustainability, and highlighted in the Internal Sustainability Review, was implemented by other Partners and evidence of its use can be seen within their final project reports and case studies of their projects.

34. The final template for project case studies or reports contained a specific section, 'Further development and Sustainability', upon which all projects were required to comment. This template was typically made available shortly after activities commenced, and as project leads were aware these case studies or reports would be made publicly available, it not only further reinforced the importance of sustainability, but highlighted that this would be a criterion by which their work might be 'judged'; this therefore encouraged sustainability to be taken very seriously.

### Alignment of Activity with Wider Priorities

35. Activities are more likely to be sustainable if they are valued by others, particularly in terms of the contribution they might make to another agenda; this might be at a personal, departmental, institutional or national level. All can act as drivers, and indicators of sustainability, but for differing reasons. For example, individual priorities may relate to job roles or responsibilities, or more typically, to institutional or departmental priorities:

**"The project team are however confident that in large part the changes will be made in a sustainable way, not least because of drivers from the University in response to employability figures and NSS scores." [Project Report, 2020 Vision: A Curriculum for Mathematics Graduates for the Next Decade, University of Birmingham]**

**"This project mirrors the ethos of the College, where all students are encouraged to become active participants in their learning." [College Dean, Adoption of SYMBΩL Project, University of Exeter]**

**"The increase in student employability represents a strategic programme for the School of Engineering and the success of this project means that this will continue as an exercise to enhance the student experience learning from its triumphs and challenges alongside our industrial partners." [Project Report, Integrating Industrial Expertise into the Delivery of an MEng Aerospace Engineering Module, Brunel University]**

36. The aim and objectives of the Programme were deliberately focused upon supporting and encouraging higher education institutions to change and enhance their practices, and to do this, the delivery model needed to allow sufficient flexibility for individual needs and priorities to be met.

**"A key piece of feedback from universities was that the order in which the stages were completed should not appear to be absolutely prescribed; procedures and requirements will vary between universities." [Project Report, Engineering Gateways PTP]**

The Programme has enabled higher education institutions to take forward individually focused activities, but within a common framework and with an embedded series of values. This has contributed to diversity and variety across the sector, but has also enabled institutional missions and priorities to be fulfilled; as a consequence activities are likely to have an increased potential for sustainability.

37. An area where this alignment is most visibly evident is within the Office For Fair Access (OFFA) and Welsh Fee Plan Agreements, which has forced higher education institutions to think about not only how they recruit students and work to increase and widen participation, but also how they will support learners upon arrival at university. It is here where it is easiest to see how institutional activities, priorities and approaches map to the work of the Programme; there are many synergies, if not explicit relationships, between the content of institutional agreements, and the work they have participated in through the Programme. Table 8.1 explores this relationship further for the 2012/13 and 2013/14 statements.

| HEI | Extracted Reference from OFFA or Fee Plan Agreement (2012/13) | Extracted Reference from OFFA or Fee Plan Agreement (2013/14) | Relation to the National HE STEM Programme |
|---|---|---|---|
| Aberystwyth University | *"We will support schemes to raise aspirations in STEM subjects from ages 7 to 14 (....... HE STEM maths challenge activities in 11 schools)."* | *"The mentoring scheme uses our undergraduate and postgraduate students in mentoring activities, working one-to-one or one-to-two on a weekly basis with students who have been identified by the schools as at risk of low attainment in Mathematics or Science subjects."* | Aberystwyth has participated in a range of outreach activities and interventions using student ambassadors. |
| Aston University | | *"STEM Ambassadors will be recruited to encourage the study of maths, science and engineering in schools. The number will rise to 30 by 2013/14…From Spring Term 2013 more than 30 Aston students will act as volunteer mentors/tutors for learners at the Academy. We will roll out our innovative Engineering CDIO interactive learning programme."* | Aston has undertaken two large projects in engineering education focused around employability and employer engagement[7]. They also participated in the UTC Practice Transfer Partnership which developed a mechanism for engaging undergraduates with the work of UTCs. |
| Bangor University | | *"We will work collaboratively across the region to extend opportunities for under-represented groups to engage with and gain experience of HE through extending STEM outreach activities and introducing taster activities aimed at specific groups to improve access to and understanding of HE."* | Involved in a range of outreach activities, including Spectroscopy in a Suitcase. |
| **University of Bath** | ***"Reduced fees of £4,500 for placements undertaken during the course of the 2012/13 degree programme for MChem Chemistry with Industrial Training."*** | ***"Reduced fees of £4,500 for placements undertaken during the course of the 2012/13 degree programme for Mchem Chemistry with Industrial Training and Mchem Chemistry for Drug Discovery with Industrial Training."***<br>***"Employability will be a University priority for 2013-14 and the particular needs of students from non-traditional backgrounds for support in finding appropriate placements and work experience will be a key focus."*** | **South-West Spoke HEI. Bath Legacy Project focused upon the deeper embedding of placement schemes across the institution.** |

[7] http://www1.aston.ac.uk/eas/research/groups/eerg/

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| **University of Birmingham** | | ***"Birmingham is setting up, from 2012, a STEM Education Centre, based in its College of Engineering and Physical Sciences, with a remit to build upon, and embed the legacy of the programme. Part of the Centre's activity will have a national focus on WP and Fair Access to STEM. We will do this as part of an agreed partnership with the National STEM Centre in York…"***<br><br>***The tutorial system provides early indications if a student is experiencing difficulties and appropriate information, advice and guidance from the range of University support services (e.g. The Academic Skills Centre and Maths Centre)*** | **Hosting of the National HE STEM Programme. The University also established a mathematics support centre through the Programme.** |
| University of Bolton | *"The University is committed to part-time, vocational and professional education; widening participation and extending educational opportunities to mature students and other under-represented groups; and to the teaching of, and research in, science, technology, engineering and mathematics, in particular."* | | Active involvement by the HEI in five projects related to these themes. Three regional action plans, and two RAEng mini-projects. A research project through more maths grads focused upon part-time learning in mathematics. |
| **University of Bradford** | ***"We lead the Northern Spoke of the HEFCE funded HE STEM programme designed to ensure universities work together regionally and nationally to widen participation in these key subjects. We have built on this role and through working closely with professional bodies we have developed a programme known as "Building STEM at Bradford".*** | ***"The University's STEM Centre will use existing best practice to support improved attainment though a range of activities with a focus on the hardest to reach communities and children from the most deprived backgrounds…"*** | **North-East Spoke HEI. Adoption and development of a range of activities through the Programme.** |

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| University of Central Lancashire | *"Students make a core contribution to many of our current outreach activities and UCLan has recently secured £53k from HEFCE to encourage STEM undergraduates, through an elective module, to develop and deliver outreach activities in schools and colleges."* | *"We are currently developing an elective module, which enables students to develop employability skills through outreach activities, made possible by an award of £53k from HEFCE through the HE STEM programme."* | A regional action plan project initiated through the North-West Spoke. |
| University of Chester | | *"Building on pilots in STEM subjects, curriculum-related subject workshops with years 12/13 and level 3 students on "Preparing for University", with assignment follow-up and academic feedback; these can also be used to support progression to HE for work-based learner. An annual year 10 STEM Awareness week and continued investment in staffing and student resources, such as 'STEM Buskers' and 'STEM Ambassadors' will further relationships between the University, schools and colleges, as well as external industry organisations."* | Chester undertook a significant project through the North-West Spoke to establish self-sustaining STEM regional networks. |
| Coventry University | *"We wish to include in our Access expenditure a proportion of the costs of our Maths Centre which has been funded by several external sources including the HEFCE CETL funds."* | *"We wish to include in our Access expenditure a proportion of the costs of our Maths Centre which has been funded by several external sources including the HEFCE CETL funds."* | Mathematics support expertise at Coventry and Loughborough was rolled-out more widely through **sigma** within the National HE STEM Programme. |
| University of Hull | *"As part of our commitment to access we shall continue to charge a lower fee for Foundation Degree programmes which disproportionately attract students from under-represented groups".* | | A Foundation Degree in the chemical sciences has been converted from part-time delivery to distance learning mode to enable participation by a wider cohort of learners. This has been extended to BSc provision. |

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| Imperial College, London | *"....the Reach Out Lab was opened in 2010 to provide additional facilities to deliver practical programmes and an experience of university for pupils aged six to eighteen, specifically from schools without ready access to laboratories."* | *"The College will engage with other institutions and organisations where such collaborations will advance its mission and educational objectives…The College has sought to maximise the cost effectiveness and impact of its school outreach activities through strategic partnership with Exscitec, an organisation aimed at providing outreach STEM activities for widening participation and gifted and talented students…The College aims to at least maintain the number of pupils from disadvantaged schools gaining experience of hands on science activities through the Reach Out Lab."* | The Reach Out Lab formed a core component of the Practice Transfer Partnership to transfer this effective practice more widely across the HE STEM sector. |
| Keele University | | *"Current undergraduate students are trained to deliver the Keelelink Ambassadors in Schools Scheme (KLASS)...this form of in-reach to schools will be retained, with expansion and development to complement other areas of focus under this agreement including specific 'Access to the Professions' sessions and STEM related sessions."* | Keele participated in three activities from the 'Menu of Activities' initiative, and has embedded these within the Keelelink programme. |
| University of Leeds | | *"We will continue to support local young people in public care through an annual seven-month study support project working in partnership with other providers across the City, including Leeds Metropolitan University and Leeds City Council. In 2011/12 we further supported this group of young people through the National STEM HE project…This year the scheme also secured one-off National STEM HE Project funding to provide training to other HEIs on ways in which they could work more successfully with young people in public care."* | Participated in numerous activities through the National HE STEM Programme; reference is to the Looked After Young People initiative established by the North-East Spoke. |
| University of Liverpool | | *"…and we also offer summer schools and Easter residential with an emphasis on STEM…Year 7 - activities linked to STEM and utilising our new state of the art central teaching laboratories, which will be made available to local schools to enable young people to take part in science activities on campus… we will offer bespoke activities for other schools, who can 'buy-in' from a menu which includes: overnight events, master classes, subject specific taster days, whole year group visits and bespoke events."* | Liverpool participated in three activities from the 'Menu of Activities' initiative, and led the regional RAEng outreach project. |

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| Liverpool John Moores University | | *"Other post-entry support includes Personal Development Planning (PDP), study support (including the setting up of a maths centre in recognition that numeracy issues can be a barrier to entry)…"* | Liverpool John Moores established a mathematics support centre through the Programme. |
| London Metropolitan University | | *"Customised additional support on study and academic skills and in Maths and English."* | Liverpool John Moores established a mathematics support centre through the Programme. |
| Loughborough University | *"We will aim to increase achievement and interest in mathematics, science and engineering as well as providing additional mathematics support for our current students."* | *"We will aim to increase achievement and interest in mathematics, science and engineering as well as providing additional mathematics support for our current students."* | Loughborough forms a founding Partner of the HE STEM **sigma** Network. Two RAEng mini-projects are focused in this area, along with a large-scale curriculum innovation and enhancement project. |
| **Manchester Metropolitan University** | | ***"MMU was also the NW "spoke" for the National HE STEM Programme, a 3 year project ending in July 2012. There are a number of positive legacies from this engagement that the University is committed to embed and sustain in the future. In particular the Programme has enabled; closer working with HEIs in the region (such as The University of Manchester and Liverpool John Moores), enhanced Outreach offerings through investment in demonstrator equipment (e.g. Large-scale Maths Outreach and Conference Kits), and more strategic targeting of WP groups through comprehensive mapping of provision across the region. It has also facilitated much wider collaboration with local FECs and employers, which has enabled the development of new Foundation Degree provision, tailored training services to those in work and possible contributions to the Higher Apprenticeship framework."*** | **North-West Spoke HEI. Adoption and development of a range of activities through the Programme.** |
| Newcastle University | | *"Continue the delivery and further development of services that support students' academic skills post entry: Maths Aid and the Writing Development Centre."* | Maths Aid utilises the Numbas assessment system which was further developed through the Programme and made available nationally. |
| University of Northampton | | *"Employability focussed programmes tackling gender imbalances will be run as part of the STEM agenda, e.g., Females into Computing, IT and Engineering."* | Participated in HE STEM Gender and Diversity training. |

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| University of Nottingham | *"The Faculties of Engineering and Science run year 0 courses for a range of students, with the Engineering course particularly attractive to widening participation students. A new pre-entry bridging course is facilitating the entry of students without the normal mathematics requirements."* | *"The Faculties of Engineering and Science run year 0 courses for a range of students, with the Engineering course particularly attractive to widening participation students. A new pre-entry bridging course facilitates the entry of students without the normal mathematics requirements."* | A collaborative project has led to the embedding of a dedicated mathematics programme for Year 0 engineering students from non-traditional backgrounds. |
| Queen Mary, University of London | *"...we will continue to support the school through a range of activities including a one-to-one-mathematics tutoring scheme and a series of "maths challenge" activities..... Schools will develop and deliver an extensive range of widening participation activities in addition to the projects offered through the central widening participation team."* | *"We will continue to commit resources to collaborative work with charities and other external organisations involved in widening participation and access. This will include groups such as…Generating Genius, which seeks to encourage and develop talented students from under-represented backgrounds to aspire to professions in scientific research, medicine and engineering."* | Implemented a series of workshops to support students from Afro-Caribbean backgrounds to apply to read STEM subjects at Russell Group and 1994 Group universities. |
| University of Reading | *"Another already successful scheme that we will wish to support in this area is the outreach work entitled 'Chemistry the Next Generation' in the Chemistry Department funded by the Royal Society of Chemistry."* | *"Another already successful scheme that we will wish to support in this area is the outreach work entitled 'Chemistry the Next Generation' in the Chemistry Department funded by the Royal Society of Chemistry…Building on very successful outreach work in our Chemistry Department, we aim to extend the number of Teachers' Centres at the University and to drive further relationships with subject teachers in target schools/colleges, through the provision of continuing professional development."* | A direct legacy from the 'Chemistry the Next Generation' project. Further activities from the RSC pilot transferred to Reading through the Programme. |
| University of Sheffield | *"Our aim is to more fully integrate the academic and personal skills development activities that are already available, and to extend the numbers of student engaging with these opportunities. These include....MASH..."* | *"Academic skills support, including targeted and tailored maths support."* | MASH stands for Mathematics and Statistics Help. The University of Sheffield forms the North-East Hub of the HE STEM **sigma** Network. |

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| Sheffield Hallam University | | *Extend capacity for mentoring, peer support and buddying schemes targeted at those students identified as vulnerable to non-completion and/or drop out… During the past year we have also piloted the STEP scheme, an initiative to build additional mentoring capacity in Faculties through our alumni links.* | The mentoring scheme involving alumni was establishing within the Mathematics and Engineering by the Programme. |
| **University of Southampton** | | ***"In order to ensure that under-represented groups such as male African-Caribbean's are encouraged to access our pre-application programmes, we are working proactively with a range of groups to take a targeted approach, for example with Generating Genius."*** | **London & South East Spoke HEI.** |
| **Swansea University** | | ***"Increased delivery of high-level skills in science, engineering and mathematics (including workforce upskilling, employer engagement activity, and employer-led part-time degree provision initiated by the National HE STEM programme)"*** | **Wales Spoke HEI.** |
| University of the West of England | | *"An outreach programme supporting progression to STEM related careers."* | Undertook project to implement more coherent STEM strategy. |
| University of York | *"The York Maths Skills Centre has been set up to provide University-wide support for elements of maths learning..... A pilot programme providing support for first year students from subjects (in the sciences and economics) whose modules include, or require, elements of algebra and calculus, has been very well utilised and we plan to expand this service to meet some additional areas of identified need."* | *"The York Maths Skills Centre has been set up to provide University-wide support for elements of maths learning, independent of departments, but in conjunction with what departments already provide. A pilot programme providing support for first year students…has been very well utilised and we are expanding this service to meet some additional areas of identified need. "* | The Centre described was established directly as part of the National HE STEM Programme through the work of **sigma**. |

**Table 8.1: An Analysis of OFFA and Fee Plan Agreements to Explore National HE STEM Programme Linkages. Spoke Partners are shown in bold.**

38. A number of the activities of the Programme also aligned with national policy drivers, and as such these too have significant implications for sustainability at an activity level:

**"The STEM projects aimed to influence the nature of provision in institutions but over the lifetime of these projects the more influential policy change around funding HE, in response to changing political requirements and national economic challenges, has tended to dominate and in some cases has influenced project outcomes and direction of travel." Kettle & Smith, Lessons Learned and Achievements from the Regional Action Plan and Legacy Projects (2013)**

39. The national importance of Access Agreements linked to a changed higher education funding landscape undoubtedly lead to increased prominence for the work of the Programme with schools and colleges, but at the same time there was the perception of a shift away from the importance of workforce development as a policy driver. Business-university interaction, however, remained a core theme despite a change of government, and this was emphasised in February 2012 by the Wilson Review. This aligned with an area where the Programme was particularly active including the development of the regional STEMBUG and BizzUP employer engagement portals:

**"I wanted to congratulate you and your team on this Business Universities project and to comment on how welcome this form of initiative is…" Sir Tim Wilson, Comments on BizzUP Employer Engagement Portal**

40. While national policy drivers impact upon the potential for sustainability, international events too can impact upon the sustainability, legacy, or strategic direction of an activity:

**"the Nuclear Island project involved the engagement of employers with national agendas in construction, nuclear power and electricity generation and the project from its inception to its evaluation spanned a period of dramatic change in public and political opinion…Notably, the Labour Government was replaced by a Conservative and Liberal coalition which had a noticeable anti nuclear stance in May of 2010. Twelve months later, the Fukushima Dai-ichi nuclear disaster which resulted from a series of equipment failures and the release of radioactive materials following the Tohoku earthquake and tsunami on 11 March 2011 further swayed opinion against nuclear power plant construction." [Project Report, Nuclear Island]**

**"The Maths Communicators course, and a case study in it, was included in the Vorderman report[8] to government on the teaching of Maths in England." [Project Report, Embedding Accredited STEM Communicator Models, University of Bath]**

41. In the case of Nuclear Island, the events at Fukushima provided a real life scenario and a focal point for discussion, and as such the prominence of the project was maintained. Further, Cogent Sector Skills Council secured additional funding from the UK Commission for Employment and Skills (UKCES) Employer Investment Fund to not only sustain Nuclear Island from April 2012 through to March 2014, but also to expand it to include learning packages for apprentices and employees.

[8] http://www.tsm-resources.com/pdf/VordermanMathsReport.pdf

### Institutional Commitment

42. The September 2011 West Midlands Enterprise sustainability review conducted a survey of project leads asking them about the support being provided to their projects by their institutions. Of the 116 responses, over 90% indicated their institution had provided some form of support to their activities, either financial, in-kind, or both. While this was promising, the survey was undertaken at the end of Year 2 of the Programme, and for many projects this reflected the early stages of their work. Such statements also need to be within the context of the Programme's framework for initiating activities which specified they should demonstrate some form of an institutional commitment to their work.

43. Having institutions formally 'buy-in' to activities at their outset was deliberate as it indicates the universities themselves, especially if the contribution is financial, are valuing the work that is taking place and investing in it; they too therefore have a vested interest in ensuring that it succeeds. The Internal Sustainability Review also provided evidence of high-level buy-in at the outset of Programme activities, and identified this as an important contributory factor towards sustainability, not least because it ensured senior level awareness of the work taking place, but also so that they might become a personal champion for the activity.

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**"Buy-in and active support from academics, Vice-Chancellors and senior executives is crucial to sustaining workforce development activity." Kettle & Smith, Lessons Learned and Achievements from the Regional Action Plan and Legacy Projects (2013)**

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With activities now having concluded their Programme supported lifetime, it is now timely to explore whether such institutional support has been maintained throughout the duration of project activities.

44. There is evidence that not only has senior level support been maintained across a range of the Programme's activities, but that it was also an important feature for projects that sought to make and embed changes to the curriculum, or engage in new approaches to delivery, if they were to realise successful outcomes:

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**"Support from senior managers with the positional authority to facilitate change was identified as being a key factor in successful implementation. Their involvement took three forms: as project leads or team members; practical support by individuals external to the projects (e.g. Heads of School); and, support from those with university-wide responsibilities." Tolley et al., Investigating Longer-Term Curriculum Change and Institutional Impact within Higher Education (2013)**

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**"Overall where senior staff have engaged with projects there has been an improvement in approaches and understanding of the benefits of employer alliances." Kettle & Smith, Lessons Learned and Achievements from the Regional Action Plan and Legacy Projects (2013)**

45. In terms of the specific support provided by senior members of staff, this has been offered in a number of differing ways:

**"The project lead is also Chair of the university's Admissions' Committee. The PVC Education is on that committee, so he was able to arrange a meeting for the project officer with the PVC - the person who really mattered. The project lead demonstrated his commitment to the project by volunteering to do two weeks in the lab demonstrating." [Academic Member of Staff, Research-Led Innovative Teaching Experiments, Durham University]**

**"The faculty and departmental management team supported the project and helped to drive it forward by leading up publicity events, ensuring that the course was allowed to be developed and approved, allocating work-loading activities against the module leaders." Kettle & Smith, Lessons Learned and Achievements from the Regional Action Plan and Legacy Projects (2013)**

46. Furthermore, there also exists evidence that senior members of staff, perhaps not involved directly with the activity at its outset, sought to understand its outcomes and then contributed to ensuring its sustainability:

**"In Chemistry and Mathematics, there was a strong sense from the management teams that the meetings had been very valuable and were worth continuing with in the longer term. Money will be set aside in the school budget in future years to ensure that the meetings can continue." [Project Report, Industrial Advisory Boards, University of Leeds]**

47. While there are many examples of senior level buy-in having a positive impact upon the outcomes of a project, there were also a very small number of examples whereby the support that was offered at the outset did not materialise during delivery:

**"…institutional support and that of senior management in my faculty has been disappointing and I feel incredibly let down and hung out to dry…" [Project Lead]**

In this particular instance, senior management support was required to enable essential changes to the curriculum for the activity to succeed; the need for such support was recognised and agreed at the outset. As a consequence, this project was unsuccessful and failed to draw down any funds.

48. Having senior management or institutional commitment to an activity at its outset is only one part of the process. Such buy-in then needs to be maintained throughout the lifetime of curriculum focused projects to help them realise successful outcomes.

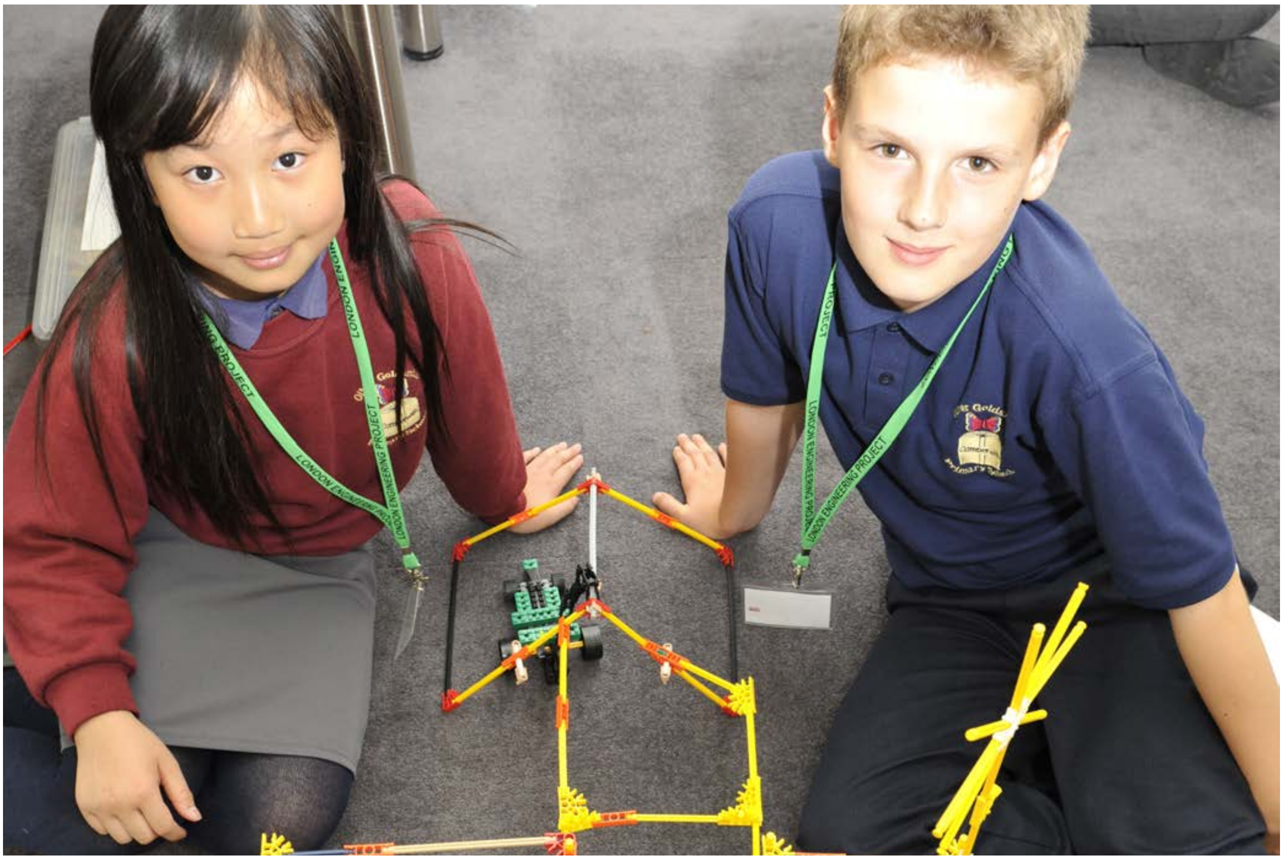
**Evaluation**

49. Evaluation is an important part of the educational enhancement process. As such, it needs to be embedded within an activity at its outset, in order to provide the data and evidence that not only allows the impact of an intervention to not only be measured, but also improvement to be identified:

**"The evaluation data as discussed…indicates the knowledge that the students gained through all three workshops is highly valuable." [Project Report, Perceptions of Year 13 Afro-Caribbean Students to Read STEM Subjects, Queen Mary University of London]**

**"The learning from this project has enabled us to identify that student confidence and fear of rejection are two of the key factors which disengage them with the placement process; subsequently we are looking at innovative methods of working with student and employer mentors to build confidence in our students and empower them in their placement search." [Project Report, Undergraduate Placements: Smoothing Transition From Education to the Workplace, University of Brighton]**

50. Throughout all stages of the project lifecycle, evaluation was an embedded feature, and as such project leads were required to ensure it received appropriate consideration; this was very similar to the requirement that sustainability be explicitly considered. In particular, all projects were required to discuss within their final case studies their approach to evaluation, and detail findings. Where a robust evaluation was not undertaken, this in itself was identified as a learning experience:



**"No formal feedback was obtained from pupils during the day, but this in itself is a lesson that has been learnt from the event. Even if the activity does prove to be a one off activity, gathering information from the group in written format should be incorporated in future activities." [Project Report, Engineering Pick n Mix, University of Wales, Newport]**

51. While evaluation was an embedded feature of the Programme's work, there is evidence that the timescale of the Programme, coupled with the longer-term nature of achieving and evidencing large-scale curriculum change, to an extent compromised the level of evaluation undertaken by some large-scale projects; for others, additional opportunities were explored instead:

**"According to a number of those questioned, the National HE STEM Programme's funding period (2010-12) allowed insufficient time for the systematic planning, implementation and evaluation of large-scale curriculum change – especially when this was linked to external as well as internal accountability." Tolley et al., Investigating Longer-Term Curriculum Change and Institutional Impact within Higher Education (2013)**

**"The team took a decision to pursue to learning opportunities provided by the touch-points and left the full evaluation, using appropriate qualitative and quantitative methods until the end of academic year – quite simply because of the opportunities provided by this project were too valuable to miss." [Project Report, Developing Graduate Employability Skills Through Industry Led Touch Points, University of Lincoln]**

On the surface this may be a 'missed opportunity', but many of the larger-scale curriculum and workforce development projects intend to undertake their evaluations after the end of Programme support:

**"The Lincoln RAPP intends to carry out an evaluation of the progress made and the programmes developed and Huddersfield is undertaking a more longitudinal study of the learners and employers engaged in the project, to assess the wider impact and evaluation of the developments." Kettle & Smith, Lessons Learned and Achievements from the Regional Action Plan and Legacy Projects (2013)**

52. Throughout the final eighteen months of the Programme there existed a genuine desire amongst project leads to better understand and further engage with the evaluation process. In part this may have been due to Programme monitoring and reporting requirements, but there may have been other drivers. There is evidence of a changing emphasis across the sector in terms of reward and recognition for teaching focused staff, and a key requirement for the academic promotion of such staff is that they demonstrate engagement with scholarship in teaching and learning. Equally, the Programme operated in a changed financial climate, and for projects seeking to attract funds in a competitive environment for further development or extension, there is a need to demonstrate efficiency or efficacy over previous approaches.

53. With evaluation being a requirement for projects, a Programme-wide approach was taken to supporting project leads in the implementation of appropriate approaches. A working group, led by the North-West Spoke oversaw the development of resources, and the organisation and delivery of

workshops and events. The events provided support at a variety of levels: a number were focused upon practical approaches to undertaking a project-level evaluation, whereas towards the end of the Programme, the focus became upon supporting those who were wishing to develop a scholarly dimension to their practice through undertaking pedagogic research:

**"I've learned lots of new techniques and being able to discuss their use in different situations has made me quite look forward to evaluating activities, something I never thought I'd say." Participant, Outreach Evaluation Workshops**

**"I found the 2 day workshop incredibly worthwhile and have left not only enthused to carry out pedagogic research but with an increased self confidence that this is something I can achieve." Participant, June 2012 Pedagogic Research Workshop**

**Dissemination**

54. Dissemination is not only an important indicator of sustainability but it was also one of the priorities for the programme over its final year of operation. It indicates there is a 'story to tell', and reflects a belief amongst those leading an activity that there is valuable learning present that is worthy of being shared more widely, and it also has a potential to directly influence institutional practice:

**"The emergent findings are in the process of being disseminated across the School of Engineering & Applied Science at Aston University via a newly developed Learning & Teaching Development Strategy. Additionally, plans are underway for the research to continue into 2012/2013." [Project Report, Regional Action Plan Projects, Aston University]**

55. A wide definition of 'dissemination' was taken during the National HE STEM Programme, from encouraging project leads to present their work at workshops, conference and events, producing guides and toolkits, publishing details of their work as either case studies, articles, or academic papers, and, in a unique and innovative scheme, enabling the uptake of practices by offering successful projects for 'adoption' by other higher education institutions in order that the developed practices might become embedded elsewhere:

**"One of the real innovative features of the Programme was the Adoption Scheme. I had never heard of anything like this being done previously, but it has meant the ideas and philosophies we initially developed are now far more widely embedded within the sector that we might ever have imagined." [Academic Member of Staff, Mathematical Modeling and Problem Solving, University of Leeds]**

56. The 'Practice Transfer Adoption' scheme involved all ten Programme Partners identifying practices and activities that were sufficiently well progressed to have demonstrated success, that had potential for wider transfer across the higher education sector, and whose project leads were willing to support those from other universities to embed these activities locally. From a significant list, 25 projects were identified for 'adoption' that met the key criteria, and advertised to the higher education community in October 2011. The subsequent selection process of the 'adopter'

HEIs initiated over 80 instances of practice being transferred through this scheme. While these 'adoptions' were one of the last Programme activities to be established, there is already evidence that these have become embedded:

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**"A decision has already been made to embed public engagement activities into the Department of Engineering as part of staff development and student recruitment activities." Extract from: 'a meta-evaluation of the adoption of public engagement training activity at seven universities across the UK' commenting upon the adoption of the activity by the University of Wolverhampton**

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**"In 2012–13 the centre will be open throughout term time for undergraduates…" Extract from** sigma **final report 2013 commenting upon the mathematics support centre at the University of Warwick**

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57. Those undertaking the activities of the Programme have also sought to disseminate their work through both presentation and publication. While such activities have been supported within the Programme structure, increasingly project leads have been disseminating through previously established external communication channels and networks and there is evidence this will continue:

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**"We have presented the website at Variety in Chemistry Education (Edinburgh, August, 2012) and at the HE STEM Conference (Birmingham, Sep. 2012). [Name removed] is further presenting to the RSC's Education Division Council in October 2012, where the future maintenance of the resource and effective dissemination will be discussed." [Project Report, Business Skills & Commercial Awareness for Chemists, University of York]**

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**"The preliminary outcomes have already been presented to educators at the Farnborough Air Show and the final report will be presented to the Space Leadership Council and the HE STEM conference." [Project Report, Enhancing HEI Engagement with the Satellite Industry for Workforce Upskilling, University of Reading]**

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58. Exploring the participation of project leads in national learning and teaching conferences in 2012 also demonstrates a commitment towards the ongoing dissemination of learning and findings. At the first Higher Education Academy STEM Conference in April 2012, nine project leads submitted, and had published, papers describing their work[9]; at the 2012 CETL-MSOR Conference[10], which has been running within the higher education mathematical sciences community since 2006, twenty-one sessions were based upon Programme projects, and a number were offered by individuals who had not previously attended this conference series. At the Variety in Chemistry Education/Physics Higher Education Conference 2012[11] in August 2012, twelve sessions were offered by project leads, and at the Engineering Education 2012 conference[12] the Programme was represented through 11 paper presentations.

59. Dissemination through printed publication has been another ongoing feature of the work of the programme; and further ensures a legacy for its work by making available a range of resources to either influence or inform future practice, or provide an evidence based starting point for the

[9] http://www.heacademy.ac.uk/events/detail/2012/academyevents/STEM_annual_conf

[10] http://mathstore.ac.uk/conference2012

[11] http://vicephec.ph.ed.ac.uk/2012/programme

[12] http://cede.lboro.ac.uk/ee2012/

development of new activities and approaches. Examples include special editions of existing newsletters[13] and journals of learning and teaching[14], to guides and toolkits:

**"Take advantage of the Toolkit produced by the EC. Seeing everything that needs to be considered/achieved in one place is very helpful and ensures that details are not overlooked." [Project Report, Engineering Gateways PTP, University of Greenwich]**

**I have been looking for something with practical tips for helping dyslexics with maths and there's not a lot out there so this really fills a gap. It's also helpful to have a relatively brief and to-the-point document to be able to give to colleagues." [Academic Member of Staff, University of Cambridge]**

**Professional Development**

60. For the legacy of the National HE STEM Programme to continue to be felt long into the future, then it not only needs to impact upon the practices of institutions or leave behind a range of resources, materials and learning, but it must impact upon the individuals who are engaging directly with current, and future cohorts of learner. As such, professional development is an important part of the sustainability process and vital for developing longer term capability within the HE sector.

61. The collaborative nature of the Programme's activities has provided natural opportunities for professional development:

**"Not only has it been an absolute pleasure, but also a fantastic professional development opportunity to be able to meet with and share ideas with teachers of A-level chemistry from across the region each teaching a different specification or in a different environment." [Project Report, Teacher Fellowship Scheme, University of Leicester]**

**"…several members of staff in each of the partner institutions have been engaged in the project work, as a result of us all running internal staff development events, and talking nationally and internationally on our project work. These staff have contributed by developing their own modules." [Project Report, Education for Professional Engineering Practice, Sheffield Hallam University, Loughborough University and London Metropolitan University]**

[13] http://mathstore.ac.uk/headocs/MSORConnections113_0.pdf

[14] http://www.aldinhe.ac.uk/ojs/index.php?journal=jldhe

62. Similarly dissemination activities have been structured to provide both formal and informal opportunities for professional development, including project leads mentoring others through the implementation of activities during the 'Practice Transfer Adoption' Scheme, the **sigma** advisors scheme, whereby experienced practitioners provided advice and mentoring to those embarking on the provision of mathematics support, and the Programme's Professional Body Partners supporting individuals within the higher education sector to adopt and embed the practices developed through the four disciplinary pilot projects:

**"Training is planned to prepare academic staff in particular to assist them with the development of courses for commercial clients." [Project Report, A partnership for Engineering CPD, Learning, Training and Knowledge Exchange, University of Bath]**

**"The course has been extremely relevant to my role within [Name removed] and has enhanced my ability to function as an education Business Links coordinator…I will be offering my services in delivering careers adviser training sessions on STEM to colleagues." Course Participant, Accredited STEM Careers Module**

**"Good for gaining ideas on small changes I can make to my practice that may make a bigger difference".Course Participant, Gender Equality Training**

**"However, there is no doubt that the [postgraduate] students who participated in this training event have learned a lot of useful skills that they are now using to good effect." [Project Report, Extending Your Outreach, University College London]**

### Developing a Community Identity

63. Creating a sense of belonging within an academic community can add real value to the work of an individual. It provides an opportunity to share examples of effective practice, benefit from the developments of others, share resources and materials, and most importantly gain support from like minded individuals; this alone can greatly aid or enhance the sustainability of an activity. If individuals obtain direct benefit from their time investment, these networks are likely to be self sustaining and can lead to the development of communities of practice.

64. Networking and bringing individuals together was an embedded feature of the Programme, and the 'Collaborative Projects', Menu of Activities' 'Practice Transfer Partnerships', and 'Practice Transfer Adopters' initiatives were all structured around this theme:

**"The help of the practice transfer partnership in the form of its members and the draft tool kit have been very useful in developing the documentation and strategies to manage the programme once it is running." [Project Report, Engineering Gateways PTP, University of Derby]**

**"The seminar I attended brought all the relevant people into one room. In a few hours I was brought up to date on curriculum options and qualifications that I could use in the UTC to be opened in a few months' time. I could make critical, informed decisions."**
**Principal designate of an aspiring UTC, University Technical Colleges PTP**

**'…in that sense it has not felt very disparate; we are all contributing our expertise.' Member of IoP Higher Education Group commenting upon Conceptual Understanding in Physics Project**

65. The sustainability of the networks and collaborations established through the programme will be discussed later within this section of the report, but the approaches utilised within the Programme have become embedded within the practice of higher education institutions who have participated actively in its work:

**"A cross-institutional Education seminar has been established and will continue to run this academic year, reporting on Education-related projects across a variety of disciplines to share best practice. A new in-house Academic Practice journal is being launched in Autumn 2012 and there is a sharing practice wiki under development."**
**[Academic Member of Staff, University of Exeter]**

**Wider Value**

66. While the vast majority of the HE STEM completed projects have achieved their original aims and objectives in full, some have achieved wider impact; this might be in addition to their original intentions or due to a changed approach. In addition to the original activity itself becoming sustainable, other sustainable changes to the practice of HEIs might result:

**"This project started out to simply add in a new MSc to the Department's portfolio. Unexpectedly, it has offered the opportunity to completely rethink our Postgraduate provision in Engineering. In addition, although we have not been able to start all the paperwork yet, it has informed us on how to deal with potential WBL provision at the Undergraduate level, which was definitely one of the key objectives of the project."**
**[Project Report, Engineering Gateways PTP, University of the West of England]**

**"These touch-points have led to a step change in practice within both the business and the University. The most immediate impact is that the School of Engineering is immediately able to accredit some of Siemens internal courses... This win-win situation encourages further collaborations and ensures that the touch-point programme will be sustainable beyond the life of this project." [Project Report, Developing Graduate Employability Skills Through Industry Led Touch Points, University of Lincoln]**

### Up-Front Investment

67. 'Up front investment' might be best referred to as 'pump-priming'; activities becoming sustainable because the substantial investment, either financial or human, is made up-front to either develop a product, revise the curriculum or implement a particular approach. Once this is complete, subsequent costs for delivery are much lower and the activity often continues through institutional support:

**"In terms of sustainability the consensus amongst those interviewed was that those changes that have resulted from National HE STEM Programme funding, which have already become embedded in the curriculum will continue to be supported out of the teaching and learning budgets allocated to Schools." Tolley et al., Investigating Longer-Term Curriculum Change and Institutional Impact within Higher Education commenting upon the Programme's projects at Loughborough University (2013)**

**"Although circumstances have prevented the piloting of modules from that would make up the new hybrid degree courses, the groundwork has been done for their implementation including: the design/validation of the new course(s); the appointment of new academic staff; and, reaching agreement with a significant number of industrial partners." [Project Report, The Hybrid Part-time MEng Degree, Lancaster University]**

**"…there is a sense that the initial hard work will be worth it in the end, with a course that will almost 'run itself'" [Academic Member of Staff, Applied Physics, University of Portsmouth]**

68. Where resources or materials have been developed, the evidence shows that these will continue to be used, not only by those who developed them, but also by others who have subsequently benefited from their use:

**"The boxes and kits will be very valuable to our maths department and central outreach teams." [Academic Member of Staff, University of Portsmouth]**

**"To date, seven of the eight trial teams have completed their case study reports and have indicated that they will continue to use the materials again in the next academic session" [Project leads for RSC C/PBL, Dublin Institute of Technology]**

**"The very positive reception the videos have received from our programme participants on the Learning and Teaching in HE programme mean that the University will continue to use the staff-facing videos in this and other staff development contexts, and the College of Engineering, Mathematics and Physical Sciences continues to make good use of the videos on their webpages for potential students. Since embarking on the project, the College has put significant additional resource into video-based material promoting STEM subjects at Exeter…" [Project Report, Becoming a STEM Enthusiast, University of Exeter]**

**"As a result of this project, the college now has a suite of marketing materials which it can use and develop on an ongoing basis to engage with females, BME or otherwise, to encourage them to choose engineering careers." [Project Report, Model for Engaging Women within BME Populations into HE Engineering Programmes in East Lancashire, Blackburn College University Centre]**

**Proven Starting Point**

69. The approach of building an activity upon previously successful work elsewhere is one that has worked to great effect within the Programme.

**"The HE STEM programme's approach in continuing to support existing centres of expertise is likely to support the development of the knowledge base." Evaluation of HEFCE's Programme of Support for Strategically Important and Vulnerable Subjects, HEFCE (2011)**

This way of working was defined at the outset of the Programme, and has been firmly embedded throughout all activity strands. Such an approach is quite likely to result in sustainability as the impact of the activity is known in advance, and is likely to have been the reason why others are interested in undertaking it. There can never be a guarantee of success, but prior learning is known and advice and guidance are available to support others with implementation. The learning curve is therefore less steep, and successful implementation can often be realised more quickly.

70. Activities that follow this approach are often built around collaborations or interactions with others. Other examples of successful Programme led and established collaborations include the wider roll-out of mathematics support centres, the IoP and Durham University led Industrial Group Projects, context and problem based learning, where the proven starting point rested within the RSC, and Virtual Experiments at the University of Southampton which was extended to six further higher education institutions through the 'Practice Transfer Adoption' scheme.

71. The vast array of work established through the National HE STEM Programme and the efforts of those who not only led activities but also strived to try and understand its impact and capture key learning, now provides the unique proven starting point for others wishing to develop similar activities within the future.

**Further Evidence of Sustainable Activity**

72. Section 12 of this report contains a number of short case studies, derived from the reports provided by project leads, which represent a 'snapshot' of the work of the Programme. These exemplars represent only a sample of the Programme's activity as its scale means all projects cannot be

represented here, although some represent collections of activity around a particular theme. The included case studies have been structured so that they demonstrate both the outcomes from the Programme's work, but also the legacy that has, or will, result.

73. The focus adopted by the Programme to enabling sustainable activity within the higher education STEM sector was through seeking to embed it within core departmental practices and provision:

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**"All three SHU mini projects are being implemented and embedded into the teaching curriculum across the courses in the engineering portfolio. E-portfolios with an academic tutoring system will be embedded from Sept 2012. LSBU projects are being embedded in the first year programme and Loughborough support systems are also being embedded." [Project Report, Education for Professional Engineering Practice, Sheffield Hallam University, Loughborough University and London Metropolitan University]**

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**"The project work has enabled the activity undertaken here to become embedded in the host department with several sources of funding being obtained to further the developments pioneered here." [Project Report, User-driven Photonics Skills Improvement via Life-long Learning (UPSKILL), Bangor University]**

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**"Statistical literacy materials have been embedded within one of our courses (aimed at environmental science students)…We ran a 15 credit course on the Plymouth University PGCAP course (for new University teachers) entitled 'Teaching Statistical Literacy'. Six people have completed the course." [Project Report, Enhancing Workplace Statistical Literacy, Plymouth University]**

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**"The Design Management Programme will be sustained at least until 2015, becoming part of other knowledge transfer activities and providing a template for the development of further projects." [Project Report, ENGAGE - STEM Work Based Learning and Employer Engagement, Cardiff Metropolitan University]**

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74. What appears to have contributed towards this success is allowing, and supporting projects to develop and identify their own sustainability plans before the activity is initiated. This allows projects to 'own' the future of their activity, and ongoing interaction from the Programme Team enabled them to ensure these plans are then put in place:

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**"However, the HE Group at the Institute of Physics has provided an important context for discussion about the Project, and served to ensure that it is embedded within the HE Physics community." [Academic Member of Staff, University of Leicester]**

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75. While activities initiated by the Programme will continue unchanged within a number of HEIs, others have committed to building upon the work as part of their own practices; this further reinforces the value of the project and may yield an even greater future legacy:

“We plan to continue to offer a semi-structured opportunity to STEM students during 12/13 and work towards the original vision of an accredited module, perhaps through attachment to the UCLan Advantage - our student experience package launched for the new academic year.” **[Project Report, Stand Out STEM Students, University of Central Lancashire]**

“We plan to build on the success of these events in the following ways…” **[Project Report, Hands on Maths Workshops, Brunel University]**

“For future trips, we intend to make more of this session…” **[Project Report, Talent2030, University of Warwick]**

“Going forward we plan to apply the resources, learning materials developed and use our experience to:

1. Roll out programme/variation of the course to a wider group of chemical companies…
2. Approach the Royal Society of Chemistry for accreditation.”

**[Project Report, Accredited, Bite Sized Learning to Upskill Chemical Industry Employees, Anglia Ruskin University]**

76. Further, examples exist of the Programme’s work having a wider, and perhaps unexpected influence upon the activities of higher education institutions:

“The project also supported an institutional review of the frameworks available at the university (which allow for workplace learning to be recognised), and evaluated them following their use so that a new framework proposal could be prepared. Whilst the final framework was not concluded or approved within the project timescales, a large number of recommendations for the framework have been made as a result of this project.” **[Project Report, Is Accreditation of In-house Training a Flexible and Responsive Model for Up-skilling STEM Staff?, Northumbria University]**

“The uptake of the toolkit by Schools extended beyond those involved in the original work included; Psychology, Biosciences and Earth & Ocean Science. Each requested a copy to aid their placement programme framework and also to train recently hired placement officers.” **[Project Report, Embedding Employability in the Student Experience of STEM Undergraduates: a Placement Toolkit for STEM Schools, Cardiff University]**

“We are considering putting an element of our Outreach activities, specifically the Spectroscopy in a Suitcase project that we have rolled out from Durham, as part of the REF return.” **[Academic Member of Staff, Durham University]**

**Sustainability at 'Sector' Level**

77. One of the key features of the work of the Programme is that it has sought to develop and undertake delivery of its activities in a collaborative manner building upon effective practice, existing expertise, and networks:

**"Using HE-STEM, Engineering Council and Royal Academy research and employer engagement expertise, the Project built on established industry networks developed through HEFCE's West Yorkshire Lifelong Learning Network (WYLLN) Advanced Engineering and Manufacturing (AEM), professional institutes, national Sector Skills Councils and industrial training organisations. [Project Report, Succeeding in Tomorrow's Engineering World of Work, University of Huddersfield]**

78. Where networks or communities of practice did not previously exist, some project leads identified the establishment of these as successful outcomes at the start of their work, for others, they developed naturally as a consequence of the activities taking place:

**"One of the features of this current project was to investigate practice within the south west region and through setting up a network, offer the opportunity for practitioners to learn from each other's experiences." [Project Report, Peer Assisted Learning: In and Beyond the Classroom, Bournemouth University]**

**"These meetings have allowed us to disseminate our findings with a wide range of individuals, start to establish networks of those people involved in employer engagement, and garner support for the project aims." [Project Report, Integration of Understanding of Offerings for Engagement Between Higher Education Institutions and Industry, University of Exeter]**

79. A question requiring consideration is whether the networks and communities of Practice established through the Programme will be sustained, and if so how? There is also the separate, but related question of the longer-term future of pre-existing networks with which the Programme aligned its activities, and to which members of the higher education community continue to contribute. Given such networks existed independently of the Programme, and as such, their sustainability is independent of its work, this is not the place for this question to be considered. Nevertheless, it remains an important issue requiring consideration.

80. Evidence exists that where networks were established to bring benefits to the activities of a higher education institution, particularly on a regional basis, these will be sustained:

**"The University of Chester takes an active role in a number of networking groups across the region…Continued commitment to these networks and partnership working with employers, other universities and colleges provides the necessary support for collaborative bids for new sources of funding for future developments and the sustainability of STEM at the University." [Project Report, Self-Sustaining STEM Networks, University of Chester]**

81. Additionally, where individuals have collaborated on activities of mutual benefit, they have indicated a commitment to further develop these links:

**"The final steering group meeting has identified several areas of the joint STEM project for taking forward as a continuation of the group's work with suggestions for funding." [Project Report, Education for Professional Engineering Practice, Sheffield Hallam University, Loughborough University and London Metropolitan University]**

**"The network of part-time course providers formed during the project is a valuable outcome. It is already clear that it will be sustained as further collaborations have already started." [Project Report, Part-time students in the workforce, Coventry University]**

82. There is evidence of thematic networks established throughout the Programme remaining active across the sector. For example, the STEM Disability Group[15] is continuing its work, coordinated by Royal Holloway London and supported by the Institute of Physics, and the Writing and Communicating in the STEM Disciplines Special Interest Group remains active out of the University of Bath. Both have an active online presence, and events scheduled well into 2013.

83. In other instances, mechanisms were put in place before the conclusion of projects to align network members with existing organisations in order that the networks established might continue as part of a larger grouping:

**"Participants will be encouraged to join the jiscmail.ac.uk/ldhen discussion group and, to join the Association for Learning Development in Higher Education." [Project Report, Peer Assisted Learning: In and Beyond the Classroom, Bournemouth University]**

84. In maintaining the activeness of existing networks across the sector, the CFE evaluation identified two mechanisms:

**"The professional or scholarly bodies, which were integral to the pilot projects as well as the subsequent Programme, have been identified by many as an appropriate means through which to continue to support HE STEM developments across the sector well into the future…The other body, whose mission aligns with elements of the Programme, is the Higher Education Academy (HEA)." CFE, Summative evaluation of the National HE STEM Programme (2013)**

[15] http://www.rhul.ac.uk/ecampus/welfare/disabledstudents/stemdisabilitytransitiongroup.aspx

The contribution of Partners to maintaining the legacy of the Programme's work will be discussed further in Section 9, but specific examples are relevant here given maintaining support for national disciplinary activities aligns with the institutional missions of the Professional Bodies involved in the Programme. For example, the RSC will maintain the Spectroscopy in a Suitcase network, and the IMA will coordinate the network of institutions hosting the regional MLOCK outreach kits. Similarly for the IoP:

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**"The Institute of Physics will continue to support the group of co-ordinators at the universities. The group have begun to discuss other joint areas of interest, such as laboratory classes." IoP Representative, Industrial Group Projects**

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Similarly the relationship developed between the Programme and the National STEM Centre will be maintained through a three-year national Programme of activity funded by the University of Birmingham. It is intended this will help maintain and develop interactions between higher education institutions and existing STEM organisations and initiatives with a view to the enhancement of university led widening participation and outreach practices.

85. While many of the Programme initiated networks will be maintained, it is important to note that some beneficial activities associated with the networks may not:

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**"…each of the regional hubs has identified mathematics and statistics support practitioners who are willing to take** sigma **network activities forward after that date in order to ensure that they continue to operate as a means of developing and sharing good practice. Nevertheless, funding is urgently needed to build on what has already been achieved by the** sigma **network, particularly to support the pedagogic research on which on-going improvements in professional practice can be based." Tolley et al., Investigating Longer-Term Curriculum Change and Institutional Impact within Higher Education (2013)**

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# A20. The Mathematical Transition: A Multi-Stage Problem?

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Michael Grove

# The Mathematical Transition: A Multi-Stage Problem?

Michael Grove
National HE STEM Programme
University of Birmingham
m.j.grove@bham.ac.uk

As Director of the National HE STEM Programme I am immensely proud of all areas of its work, but one that I continue to take particular personal and professional interest in is the teaching and learning of mathematics at the transition to university. This naturally reflects my background within the Higher Education Academy Maths, Stats & OR Network, but more so the fact that I also teach both Foundation and First Year mathematics courses at two Russell Group universities.

Taken as a whole, Mathematics and statistics form an important component of many degree programmes. There exists, however, a well-documented problem with the mathematical preparedness and skills of undergraduate students as they commence their university studies, and not just within the Science, Technology, Engineering and Mathematics (STEM) disciplines. Anecdotal evidence of such a problem has existed for some time, and perhaps longer than we might imagine. In 1805, the Reverend John Toplis submitted a letter to the Philosophical Magazine entitled 'On the decline of mathematical studies, and the sciences dependent upon them' [1], expressing concerns about the lack of desire for the mathematical sciences. In the introduction to their influential book, *'What is Mathematics'* [2], first published in 1941, Courant and Robbins noted: *"Even more, perhaps, in a time when everything depends on education toward reason is mathematics the unparalleled agent of mental discipline and the embodiment of constructive and inventive thinking. Unfortunately, these aspects of mathematics have been greatly neglected in the recent past. Most of us have been subjected to a routine mathematical training in high school."*

A detailed understanding, however, of exactly what constitutes or contributes to a 'mathematics problem' is relatively recent (the first attempts to capture documented evidence go back around 15 years [3]). Yet despite the time that has passed and the significant work that has taken place, recent reports continue to provide robust evidence of ongoing concerns. It therefore seems timely to ask if this is the same problem as that documented 15 years ago?

The report, '*Measuring the Mathematics Problem*' (2000) [4], recognised the existence of a mathematics problem within the disciplines of mathematics, engineering and physics, and highlighted two contributing factors in particular: *"insufficient candidates with satisfactory A-level Mathematics grades for the number of degree places available"* and *"the freedom of A-level students to choose Statistics as an alternative to Mechanics"*.

Since 2000 we have seen a substantial increase in the number of students studying mathematics at A-level, and in the percentage of those awarded the highest grades. Almost 83,000 students participated in examinations last year, a 20 year high, and rapid growth has also been seen in Further Mathematics with A-level and AS-level entries in 2011 increasing to almost 12,300 and 18,500 respectively. For 2011 completers, mathematics is now second in the top ten list of most popular A-levels, although there is a need to remain cautious as there is evidence that students at private schools are twice more likely than their peers in comprehensive schools to study mathematics at this level.

***"A key finding of the Institute of Physics report is that many of the academics surveyed believe that current mathematics and physics provision at A-level leads to students learning by rote rather than through their own independent techniques."***

While there has been growth in mathematics A-levels, there has also been growth within the HE sector. In recent times growth within the STEM disciplines has, on the whole, greatly exceeded the sector average. Comparing the period 2005/06 to 2009/10, overall full-time student enrolments within higher education increased by over 11% but growth in the STEM disciplines has, on the whole, greatly exceeded this. Mathematics increased by over 26% (+5,460 students), physical sciences by 16% (+7,370 students), engineering and technology by 18% (+13,575).

Studying the average tariff data for 2009/10 and 2011/12, presented in the Guardian university rankings, and which indicates the average number of UCAS points students possess on entry to only mathematical sciences degree programmes, reveals some interesting patterns. Averaging these across all institutions who provided data shows that the average UCAS tariff for the mathematical sciences increased by 10 points to 386 points in 2011/2012. While not conclusive, it reflects the general trend observed of an increase in the qualifications of incoming students being accepted for university entry to study mathematics, although it is certainly not a universal pattern for all the HEIs for which data was available.

There has been growth in both A-levels and university courses within mathematics and disciplines that contain a significant mathematical component, and it is evident that there are now more learners who have higher pre-entry qualifications in mathematics than previously. Despite this, the mathematics problem continues to exist, suggesting it is no longer due to an insufficient number of A-level candidates with the necessary grades. The Institute of Physics, one of the Partners of the National HE STEM Programme, recently produced a report [5] entitled *'Mind the Gap: Mathematics and the Transition from A-levels to Physics and Engineering Degrees'* which indicates many physics and engineering academic members of staff feel new undergraduates within their disciplines are underprepared as they commence their university studies due to a lack of fluency in mathematics. In addition, the report also highlights the concerns that students themselves are now beginning to articulate in relation to their mathematical skills prior to university entry. This is despite the evidence that they are typically arriving at university with increased mathematical grades, and provides further evidence of issues with pre-university qualifications rather than the individual students themselves.

The '*Measuring the Mathematics Problem*' report recommended that *"Prompt and effective support should be available to students whose mathematical background is found wanting"*, and while it is evident that the mathematics problem has not been solved, significant progress has been made. An ample supply of free, good quality resources are available to help any students serious about remedying their shortcomings, and to help academic and support staff who aspire to assist students who struggle at the school-university interface, and a significant proportion of universities have invested substantially to put palliative mechanisms in place, for example mathematics support centres [6]. It is also the case that there are, or have been, several high profile, well-resourced national projects designed to increase the supply of mathematically qualified school leavers, and to improve teaching quality and continuing professional development of mathematics teachers.

It might be argued that there are now three aspects to the mathematics problem we currently observe as students make the transition to higher education study:

1. A lack of core mathematical knowledge and concepts traditionally expected at the transition to university study;
2. A lack of fluency in applying mathematics and specifically an inability to model and solve (unfamiliar) problems;
3. Students, not studying sufficient mathematics prior to university entry particularly in disciplines outside of engineering, mathematics and physics.

The effects of each are not observed equally across disciplines. My personal experience indicates that for first-year mathematics and physics students, the dominant issue appears to be an inability to apply mathematics rather than an inability to undertake the 'routine processing' of calculations; in particular, students struggle to identify the techniques and approaches required to solve problems. This should not, however, be taken to indicate that issues do not exist with students' core knowledge in these disciplines, but merely that the mathematics issues we are facing within higher education are changing and these require differing approaches to their solution, particularly when considering disciplines beyond engineering, mathematics and physics.

There is clear evidence that the number of disciplines impacted by the mathematics problem has broadened, from its initial impact upon the disciplines of mathematics, engineering and physics, with issues now being seen within chemistry, and the biological, health and social sciences. A different contributing factor is responsible which was highlighted in a recent report by the Advisory Committee on Mathematics Education (ACME) [7] that found around 210,000 students out of the 330,000 that are studying courses that require mathematical knowledge beyond GCSE do not have the required skills, leading to challenges for both the universities and students involved. Here the issue is that students on a wider range of higher education courses are either not aware that the further study of mathematics would be highly beneficial to them or universities are not requesting they study it. As a consequence, students are arriving at universities without having studied the necessary mathematical courses, and for many, they may not have studied any mathematics for two or three years prior to university entry. This is something we can collectively influence and address through our university admissions processes.

So where should we now focus our efforts to address this problem given the progress we have made to date? A key finding of the Institute of Physics report is that many of the academics surveyed believe that current mathematics and physics provision at A-level leads to students learning by rote rather than through their own independent techniques. A 2008 report entitled *Newton's Mechanics – Who Needs It?* [8] highlighted similar concerns and linked this to a decline in the ability of undergraduate students to model and solve problems at the transition to university. Our efforts should now be to address the lack of fluency amongst incoming undergraduate cohorts in the application of mathematical techniques to unfamiliar exercises, problems or scenarios. The current A-level system does not allow students sufficient opportunity to apply their mathematical skills, particularly if they choose not to study modules of mechanics. It is interesting to note that those students who responded to the Institute of Physics survey and had studied components of further mathematics prior to university entry felt better prepared mathematically for their studies and indicated they felt they required less support. Our interventions, particularly during the first year of university study, need to focus upon allowing students to model scenarios, solve problems, and generally have extended opportunities to engage with the application of mathematics to disciplinary contexts. These are in addition to ensuring ready access to the existing support measures we have developed remains available.

The fact that a mathematics problem continues to exist many years on may imply a gloomy picture, but the response of higher education to it does not. Measures have been put in place nationally to ensure that all students embarking upon undergraduate programmes with a strong mathematical content have access to resources that will ease their transition into higher education. Universities are adopting a number of approaches to tackling transitional problems, for example by the provision of summer schools, bridging mathematics courses and through mathematics support centres which many universities have now established. Universities now also have access to a range of quality resources that have been produced directly to support students: the FDTL4 project Mathematics Support at the Transition to University has developed mathtutor, the FDTL4 project Helping Engineers Learn Mathematics (HELM) produced workbooks, and the mathcentre project has produced numerous resources as well as an online resource bank. In addition, through the work of the National HE STEM Programme and the sigma centre of excellence in mathematics and statistics support, a national mathematics support network has been established for higher education staff working to address the student mathematical transition to higher education. The Programme also has several other projects active in addressing the issues described. For example, at the University of Leeds a project focused upon enhancing students mathematical modelling and problem solving skills at the university transition now involves fifteen departments within eight HEIs who have all made changes to the way their programmes of study are delivered to ensure these vital mathematical skills are effectively developed.

Given the multi-faceted nature of the mathematical issues we experience across a range of disciplines in higher education, it may be that using the term 'mathematics problem' is no longer appropriate. Perhaps we might consider thinking in terms of the 'mathematical transition' as students commence university study and its different meaning to disciplines. There is certainly a valid argument for thinking this way. With the recent changes to university fee structures, the transition to university study is a priority for many HEIs and is explicitly documented within their Access Agreements. Highlighting the important role of mathematics to the university transition, and not just within the STEM disciplines, would maintain its profile and hopefully help ensure the continuation of the successful work initiated to date.

Whatever we choose to collectively call the issues, the ongoing existence of mathematics problem prior to university entry clearly requires adjustment to the pre-university curriculum. Members of the Programme Team, and by this I include those from the HE sector who are participating in its activities, would be willing to contribute to the redesign of the existing GCSE and A-level curriculum and there is a very natural role for higher education here if government so chooses. Until then, we must continue to support students to develop and enhance their mathematical skills upon university entry; I am delighted we are working with the sector to do just that.

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## sigma Prizes for Outstanding Contribution

In 2012, the **sigma** network (formerly the Centre for Excellence in university-wide mathematics and statistics support) intends to award two personal prizes to individuals who have made significant contributions in the field of mathematics and statistics support. These prizes will be awarded at this year's CETL-MSOR Conference Dinner on Thursday 12th July 2012.

### Prizes and Eligibility

- One prize of £1000 to an individual employed in a higher education institution (UK or overseas) who has made a sustained contribution to mathematics and/or statistical support – the sigma Outstanding Contributor 2012
- One prize of £1000 to an individual employed in a higher education institution (UK or overseas) who has made a notable contribution to mathematics and/or statistical support at an early stage of their career – the sigma Rising Star 2012

Nominations are now being sought and must be submitted by 5th March 2012. Full details (including nomination forms) can be found at **http://sigma-network.ac.uk/blog/archives/sigma-prizes-for-outstanding-contribution**

For further information or informal enquiries please contact Dagmar Waller, **sigma** Assistant Director (**d.a.waller@bham.ac.uk**).

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# A21. An Impact Framework Approach to Project Level Evaluation

**Grove, M.J.** (2012a). *An Impact Framework Approach to Project Level Evaluation*. In: *Evaluating your HE STEM Project or Activity* (pp. 8-11). Birmingham, UK: National HE STEM Programme. ISBN 978-0-9567255-4-7. Available at https://www.birmingham.ac.uk/Documents/college-eps/college/stem/evaluating-your-hestem-project-final.pdf

## An Impact Framework Approach to Project Level Evaluation

**Michael Grove, University of Birmingham**

It is often the case that the evaluation of a project or activity is one of the last stages of the educational enhancement process to be considered. Sometimes this is only undertaken once a project is in its final stages, or on other occasions it may take place once a project has completed. Planning the evaluation during the design stage of a project and embedding it throughout offers many additional benefits. It provides formative feedback that can enhance delivery or give rise to additional, and often unintended, benefits; it enables evidence of impact and effectiveness to be collected naturally; provides a level of external, and stakeholder, input to the design, development and delivery of the activity; and can identify additional areas for further work or study. As well as identifying what has worked, and more importantly why it has worked, it can enable an understanding to be developed of why some approaches aren't as effective as perhaps might have been reasonably expected at the outset. Additionally, undertaking a robust evaluation is critical to ensuring appropriate recognition not only for the project and its learning, but also for those individuals involved in the work taking place.

Project level evaluation, of either a single activity or a collection of activities, can be designed around an impact framework. All projects are typically required to demonstrate visible impact if their longer-term sustainability is to be ensured, or if they are to attract additional support and investment. In particular, any new educational enhancement activity needs to demonstrate its value beyond previous practice. Such value might be financial, in terms of cost savings, but may also be the additional effectiveness of the approach at achieving a desired outcome, or increased efficiency of delivery.

The evaluation framework described in Table 1 builds upon a model first developed by Donald Kirkpatrick, and applied to the evaluation of Higher Education Academy Subject Centres in 2008/2009 by David Baume. It is based upon a hierarchical application of what might be termed key performance indicators that move towards increased levels of impact for a project or activity. At its lower levels, the framework explores general awareness of a project and wider engagement with the work taking place. At its higher levels it explores the acquisition and application of learning, the influence of the project upon activity and practice, and concludes at the highest level with the longer-term sustainability of the activities and practices initiated by the project.

The framework defines a series of indicators against which those undertaking educational enhancement activities should consider collecting evidence during their work; not all indicators will be relevant for every project. For each indicator, the question should be asked '*How will I know if this level has been successfully achieved?*' This will help define a series of evaluation questions that might be asked and begin to define the evidence or information that could potentially be collected. Such information might then be incorporated within a case study or published article arising from the work undertaken.

Underpinning each question is the need to obtain data and evidence which will be both qualitative and quantitative, and which is required to justify and validate any statements, conclusions or findings identified by the work. The framework does not describe the types of evidence that might be collected or indeed even how they might be collected as this will vary from one activity to another; a variety of methods are available to project leads and not all will be equally appropriate.

### References

*Evaluating Training Programs: A Collection of Articles*, Donald L. Kirkpatrick (1975)

Baume, D. (2009); Private correspondence

| Level | Key Performance Indicator | Explores | Questions to Consider |
|---|---|---|---|
| 1 | Awareness | **The extent of awareness of the project, its resources and opportunities.** This may be localised, for example a department or faculty, or may be wider to encompass an institution, range of institutions or educational sectors. It will extend beyond exploration of the awareness of the existence of the project to exploring wider understanding of what it is seeking to achieve. | To what extent are key stakeholders aware of the work being undertaken?<br>Is the awareness effective? Do others understand what the project is seeking to achieve?<br>Does more need to be done to raise awareness of the project and in what sectors?<br>Are there opportunities for others to contribute? |
| 2 | Perceptions | **The current reaction or perception of others to the activities, resources and opportunities made available by the project.** This explores the views of others towards the project and may be provided at its outset (baseline), at its conclusion, or at strategic points in between. It provides an opportunity to generate engagement with others, and might include a consultation to help shape or develop an activity, or obtain direct feedback from staff or students as to the perceived benefit or impact or an activity or resource. Such an analysis is important for understanding and managing the expectations of others. | What do wider stakeholders think of the project?<br>Do external perceptions align with the scale and scope of project activities?<br>Do external expectations need managing, or internal (institutional) expectations revising? |
| 3 | Engagement | **The extent to which the project has engaged others in its work.** Each project might have a core delivery team, but others may become involved in its work; this could include staff, students, employers, or senior management. Each will be involved in differing ways, for example it might be the extent to which a senior manager has championed or supported the activity, the number of students who have participated in delivery, the number of individuals who have attended events or contributed examples of practice. Often, engagement extends beyond the original identified stakeholders and beyond the planned institutions; all are such examples of additional impact. | How has the project worked with its target stakeholders?<br>What wider opportunities for engagement has it provided?<br>To what extent have others been involved or become involved in the project? How has such engagement arisen? |

| Level | Key Performance Indicator | Explores | Questions to Consider |
|---|---|---|---|
| 4 | **Dissemination** | **The extent to which the project or activity has shared its learning and findings.** Dissemination is an important part of the educational enhancement process, and is a clear indicator of impact. It might include the number of resources produced, events offered, funding provided, engagement with a project website, or networking opportunities provided to others. Data captured should extend beyond only quantitative data (for example number of events, resources, or website 'hits') but should explore qualitative aspects, for example, who were the audiences for dissemination and how did they contribute? | What has the project done to disseminate its work?<br>Has the project enabled the sharing of ideas and effective practices with others?<br>Who were the stakeholders for dissemination and to what extent has there been internal and external dissemination? |
| 5 | **Learning** | **An analysis of the learning that has emerged from the work and its wider implications.** This includes 'knowing' what the project is doing/has done, but also understanding what the findings and outcomes from the activities are and their potential wider implications. This will include intended outcomes, but also unintended ones. Identifying learning will include 'what works' (and why) but it is equally important for informing the activities of others to identify 'what doesn't'. | What has the project achieved? Has it had the desired impact? How do you know it has had this impact?<br>Has it met its aims and objectives? How do you know?<br>What is known now that perhaps wasn't before? Or is evidence now available to support (or contradict) a particular hypothesis or 'position'?<br>What additional learning has been generated beyond the original intended outcomes?<br>How does the learning align with existing literature or theory? |
| 6 | **Application of Learning** | **The extent to which the learning has been applied or will be applied.** This might include how the learning has influenced and informed the project as it has developed, or how the ideas have been subsequently utilised by others. It may include intent (ideas and proposals) for additional work that builds upon the learning generated, or where learning has been (or will be) applied in a different, or wider context. For example, work at module level might have influenced activities at a programme or departmental level. | What wider interest has there been in the findings from the work by others? What have others done with this learning?<br>Are the outcomes or outputs from the work being utilised by others? What impact has this had? Is there intent from others to do so?<br>What enhancements or changes have been made as a result of the activity?<br>Is there an intent to apply findings more widely or extend the project to a different context?<br>How was the project modified in response to the learning that emerged?<br>What would you advise others repeating the activity to do differently and why?<br>How have the staff, students or other stakeholders involved benefited from the activity? |

| Level | Key Performance Indicator | Explores | Questions to Consider |
|---|---|---|---|
| 7 | Practice Change | **The extent to which the project or its activities have influenced future practice and policy.** This extends beyond intent to change, and describes the direct consequences of the activity undertaken upon the future practices of both individuals and higher education institutions. It explores how the activities have influenced policy (at departmental, faculty or institutional levels) or enhanced staff capability or capacity. It will describe what is now different or will be different as a result of the work and represents a direct commitment to continued application of the learning and activity. It may also describe changes that have taken place beyond the original organisations and individuals involved (wider influence). | What is now taking place within higher education institutions that wasn't previously and can be directly attributed to the work of the project?<br>How has the project helped changed the practice of HEIs?<br>How has it influenced the practices of other members of staff?<br>How has the learning or activity influenced (current or future) policy at departmental, faculty or institutional levels? |
| 8 | Sustainability | **The extent to which the activities initiated or supported will continue beyond their funded lifetime.** This describes the commitment of the institution and individuals within it to continuing the activity or embedding the learning more widely. It may be that the activity continues in a modified or alternative form based upon the learning that has been generated or due to wider circumstances; this too should be captured and recorded as an indicator of impact. | Will the practices developed be sustainable (continue) beyond the funded lifetime of the project? Will this be in its current or modified form?<br>How has, or will sustainability be achieved? What indicates sustainability has been realised?<br>What is the commitment of the HEI or the individuals within it to both the activity and its future legacy? |

Table 1: Project Level Impact Evaluation Framework

# A22. A resource and activity centre for mathematics students beyond their transition to higher education

Croft, A.C., **Grove, M.J.** & Bright, D. (2008). A resource and activity centre for mathematics students beyond their transition to higher education. *MSOR Connections,* 8(1), pp. 11-16.

Tony Croft, Michael Grove and Daniela Bright

# A resource and activity centre for mathematics students beyond their transition to higher education

Tony Croft
*sigma* – Centre for Excellence in university-wide mathematics & statistics support
Loughborough University
A.C.Croft@lboro.ac.uk

Michael Grove
Maths, Stats & OR Network
University of Birmingham
m.j.grove@bham.ac.uk

Daniela Bright
*sigma*
Loughborough University
D.L.Bright@lboro.ac.uk

*Mathematics support* is a broad term now widely interpreted within higher education as embracing facilities offered to students that are provided *in addition* to those which may traditionally have been available such as lectures, tutorials, and problem classes. Mathematics support is often provided outside of academic departments and perhaps by staff who are not formally teaching the students. Historically, such provision has been focussed upon non-specialist students, for example those on engineering programmes especially as they enter university and throughout their first year. In 2005, ***sigma*** – the Centre for Excellence in Mathematics and Statistics Support was established as part of HEFCE's initiative to establish Centres for Excellence in Teaching and Learning (CETLs). It aims to develop provision not only for students who are struggling with basic mathematics at the transition to university, but also for other groups for whom a need can be identified, or for whom existing provision can be enhanced. Thus we are in the process of redefining mathematics support, to move beyond a remedial model to one of enhancement.

A particular group that is now benefiting from such provision has been single and joint honours mathematics students, studying at Loughborough University, and who are beyond their year of transition into higher education. Sigma funding has enabled the development of a *resource* and *activity* centre for these students. This article explains the rationale for the centre in terms of both local need and research findings nationally which suggest such a development might be a useful enhancement to the student learning experience. We provide an outline of underlying theoretical considerations, a research methodology which has, and is, being used to inform developments, together with practical information about the centre's creation, and its early evaluation.

## Rationale and theoretical considerations

There is a substantial body of research in the socio-cultural literature which suggests that mathematics teaching to undergraduates is 'excluding', and that it treats students as unimportant outsiders with the effect that many are marginalised [1,2,3]. A relevant contribution in this area is the ESRC-funded project, *Student Experiences of Undergraduate Mathematics* (SEUM) led by Wiliam [4] (elements of which have also been reported in [5,6]) which examined single honours mathematics students in two large research-led universities. The project report noted that ***"for many of those staying [on the course] the problems of coping with the work were accompanied by growing disillusionment with mathematics."*** This work sought to identify factors which engender positive attitudes both to students' own competence and to mathematics as a discipline. A major finding in relation to student experiences related to the extent to which students felt part of a mathematical community. In one of the two universities, students had their own mathematics study areas close to staff offices, and students could thereby interact readily with lecturers as well as make appointments to discuss their concerns. In the second institution, a large number of the students lived at home and problems with time-consuming commuting, combined with very limited social space for mathematics students resulted in a sense of isolation. Students in that institution also reported making less use of lecturers and tutors outside teaching sessions, and there was sometimes a low attendance at lectures.

Solomon [7] in her study of undergraduate mathematicians in another research-led university reported a pervasive identity of 'not belonging'. In order to understand how these students can develop negative relationships with mathematics, it is useful to explore their identities in terms of their membership of a community of practice [8] and the extent to which they experience studying mathematics in terms of ***"legitimate peripheral participation"*** [9] – that is, as a novice who nevertheless feels guided and supported by experts. This socio-cultural perspective characterises identity as the experience of a common enterprise, with shared values, assumptions, purpose and rules of engagement and communication: ***"we know who we are by what is familiar, understandable, usable, negotiable; we know who we are not by what is foreign, opaque, unwieldy, unproductive"*** [8]. The research literature reports that many students in fact tend to describe themselves as outsiders, as lacking control over their mathematical knowledge and its learning; many follow rules without understanding, and consequently they are vulnerable to failure – staying with the subject is possible only as long as they can do it, and this ability can fail at any time.

Wiliam [4] reports that many students choose to study mathematics at university because they find it easy at A-level. Thus they risk losing motivation when the work becomes more difficult and success is no longer guaranteed. Of particular relevance here is their finding that students who had more positive attitudes to studying mathematics were those who shared their ideas and problems with other students. Feeling part of a mathematical community emerged as a crucial factor in the student experience, and in the SEUM project, this community focused on a particular physical space within one of the participating universities.

In July 2007, the National Audit Office (NAO) published a report [10] on the retention of students within Higher Education. Although the report was not specifically targeted at the mathematical sciences, there are several areas where it recommends that an institution can target its work in order to make a difference to student retention. In particular, the report describes that the approach to retention should be a positive one, and that it should provide students with opportunities to improve their grades rather than simply addressing any gaps within their knowledge. Thus our intended shift of mathematics support from a remedial to an enhancement model aligns well the NAO recommendation.

Loughborough University, which was not one of the three universities researched in the studies cited above, has an undergraduate population of around 600 students based in the School of Mathematics studying on single and joint honours mathematics programmes. Whilst areas for private and group study can be found in the University Library and in smaller social learning spaces incorporating cafeterias at locations around the campus, the School of Mathematics itself consists largely of staff offices with little teaching space and no social or learning spaces for student use. Though a significant number of students live in halls located conveniently on campus, and though these are appropriate for individual study, the majority of students move off-campus and out into the town for their second year. Thus opportunities for students to work together within the School confines are rare and the scope for students being isolated from the rest of the mathematics academic community is great.

There is a mathematics learning support centre within the School and this is well-used by students from many departments. This was established in 1996 to offer one-to-one help, primarily to engineering students, and to first year mathematics specialists. Prior to 2005/6 students entering year 2 continued to use the centre as social learning space, although first year students were prioritised as far as one-to-one help was concerned. In 2005/6 the Centre had become so busy that use was restricted to first year mathematicians so removing entirely any learning space for those in year 2 and beyond. This step, albeit taken reluctantly, was pragmatic. With the opportunity of CETL funding we sought to address this. At the same time, we set out in this project to try to overcome some of the factors which generate identities of non-participation or marginalisation. We were interested in ways in which support for undergraduate mathematicians beyond the transition might be enhanced through the provision of dedicated, well-resourced social learning space within the heart of the School of Mathematics, and also through new activities designed to take place therein. The intention is that this space is used not only to encourage students to work independently and together, but also for staff-student interaction.

An expectation of the CETL initiative is that developments will be research informed and research-based, and so not only are we engaged in the practical aspects of delivering a resource centre, we also seek to ensure that we develop a research programme to guide its development and evaluation, and to contribute to the knowledge base in our field. The overall aims of the project are to improve the engagement of second year undergraduates, to improve their resource base, to develop a more positive relationship with mathematics, and to mitigate against the development of identities of not-belonging. The methodology adopted is described next.

### Methodology

The methodological basis of the research is Lewin's model of Action Research (e.g. McNiff [11]), appropriate because it provides a structure for the identification of strategies to make informed changes to practice. This involves fact-finding to obtain a fuller description of the issues being faced, literature review and pre-action prior to implementation of the Action itself. The resulting Action, in this case development of additional support structures, is evaluated in conjunction with the students themselves. Amendments and refinements are made before the Action Research cycle begins again. We intend to implement at least two cycles. This methodology is shown schematically in Figure 1.

### Pre-action and Data Gathering

In November 2006 two focus groups were held with second year undergraduate mathematicians. These students were chosen from a second year cohort of approximately 150 students, of which 58 were single honours. A decision was made to constitute the focus groups from those identified as being overall first class or upper second class honours students at the end of their first year, of which there were 22. This was a deliberate decision because, historically, mathematics support has primarily concentrated upon those students with mathematical deficiencies and this new programme of activity intends to shift the balance to in order enhance performance and learning experience for even the best of students. The two groups each comprised five students.

Students were asked about their learning of mathematics at University generally, and particularly about their use of the existing Mathematics Learning Support Centre. Not all students had used it, but those that had described how they were using it both to seek help from staff and as social learning space.

> ***V - I used to go and sit up there, and you'd have quite a few people doing the same coursework, throw ideas about how to answer the questions.***

> ***B- …. I think it's just handy if you work in there, and you come across something difficult, if the lecturer happens to be in there they can help. I mean I have been in there before, just worked, never had any help.***

A repeated opinion was that in the second year, the stakes are higher, but the support on offer is reduced:

> ***B - ... I normally use it when, to be honest I normally go in when the lecturer's on duty ... but its just a bit annoying that if you turn up before a 1st year, they get help, especially when it doesn't count with them.***

Not surprisingly, when asked whether an area dedicated for their use would be welcome there was enthusiasm. But some of the reasons for that enthusiasm were illuminating:

> ***V - I think that when it comes to exam time you do need to be out, because sometimes you don't want to be in the house revising, you just want to go somewhere and the library round exams is so full and there's really nowhere else for you to go.***

> ***D - when you go to work, the people in there are going to be doing the same stuff as you anyway, so you get help with each other.***

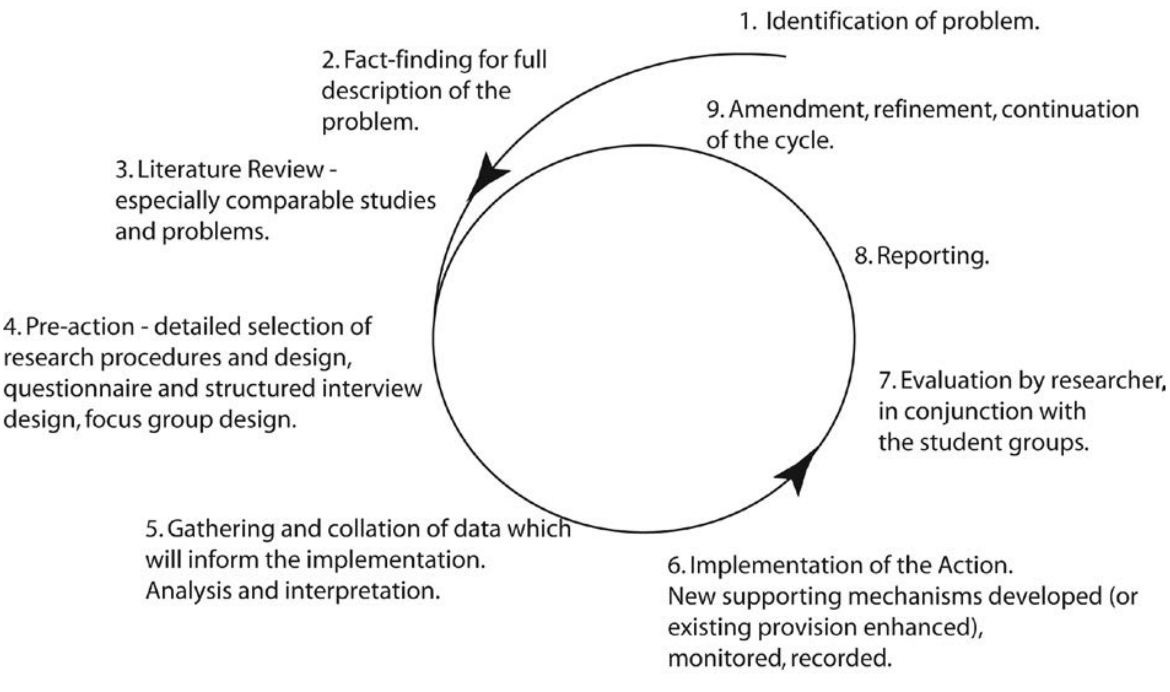


**Fig 1 – The Action Research cycle – adapted from Lewin (McNiff, 1988).**

***V - there will be more people who know what you're on about when you try to ask a question.***

***B - if it was just close to the maths [learning support] centre as well that would be pretty good.***

As it turned out, the new centre was eventually located adjacent to the existing centre and this has proved helpful as we detail below.

It is interesting to note that the views described above echo some of the emerging findings from a related, simultaneously undertaken, programme of activity which explores the prior mathematical experiences of postgraduate students. It seeks to better understand progression patterns and motivating factors for continued study within the mathematical sciences, and although this work is still at an early stage, some interesting findings have emerged. The students themselves comment that:

- mathematics support for mathematics undergraduates is needed more at the transition into year two, as new and more abstract topics are introduced;
- informal peer support is the first choice of many for mathematics support;
- many students welcome the opportunity to both give and receive formal peer support;
- postgraduate communities of practice within the department are important in order to encourage a sense of belonging.

Both these programmes of activity - our work with postgraduate students and with second-year undergraduates - indicate that many, though not all, students value opportunities to interact with each other on learning activities as much as they value direct one-on-one support from an academic member of staff. There is a greater emphasis on the development of student learning communities throughout undergraduate programmes than may have first been realised, and these views validate similar findings in [4].

## Implementation

Fortuitously, space became available adjacent to the existing Centre, and within the School of Mathematics, and a successful case was made to house the new facility there. The room, 46 square metres, was refurbished to include whiteboard, tables around which up to 20 students can work, five computer workstations, 7 low chairs and tables, fixed data projector, DVD player and video player. All recommended textbooks for second and third year mathematics modules were bought to provide a core of resources. These were supplemented by user guides on various computer packages. Students are able, independently, to connect their own laptops to the data projector in order to practice the individual and group presentations required as part of their modules. Such a facility has not hitherto been available. A laptop is also available for short-term loan.

**The Resource and Activity Centre**

At the beginning of the academic year 2007/8 the new centre was promoted to second and third year students via personal invitation, via email and via an advertising flyer. An initiative, *Second Year Success (SYS)* was developed by two members of academic staff, one from within the Mathematics Education Centre at Loughborough and one from a nearby University who was engaged as a consultant. In the first term (2007/8) this initiative consisted of two workshops which were formally scheduled into students' timetables. The first focussed on a review of year 1 modules, information on how the year 2 programme follows on from year 1 and on how this will lead into year 3. Part of the workshop was concerned with accessing resources students have available to them electronically. Finally, there was a timetabling exercise intended to help students organise their time better. The second workshop focussed on reading theorems and proofs. Discussion of the *SYS* initiative will form the basis of a future article.

## Some preliminary evaluation findings

At the time of writing, the centre has been open to students for one term, and so the evaluation of its use and impact is still very much in the early stages. However, a number of interesting findings are already beginning to emerge from the data collected. Evaluation has been carried out using a mix of quantitative and qualitative methodologies. Usage data have been gathered which show which students are using the facilities, how often and when. Interview data have been gathered to elicit students' views. A series of observations have been undertaken to study the ways in which the centre is being used, and how students interact with each other.

Table 1 shows the number of visits made to the centre each week of the Autumn term of 2007/2008 [Week 10 data are not shown due to a system malfunction]. At the end of term, a total of 125 student visits had been made by a total of 48 different students. This information is collected by a swipe-card system upon entry to the centre. The centre is not staffed and we are aware that not all students swipe-in. Consequently actual usage is known to be higher than indicated in the table. As is to be expected, the number of student visits increased as the term progressed as more students became aware of the existence of the centre.

An interesting breakdown of the total number of visits made by individual students can be shown within Table 2. Although more Year 3 students visited the centre than second year students, 61% of these only attended once; this should be compared to the 35% of second year students who only used the centre once. It is worth noting that 41% of second year students used the centre more than three times and clearly these students are finding the provision useful. The reasons for these usage patterns will be investigated further as the year progresses and more evaluation data become available.

| Week Number | Number of Student Visits | | Weekly Total Visits |
|---|---|---|---|
| | Year 2 | Year 3 | |
| 1 | 0 | 0 | **0** |
| 2 | 2 | 2 | **4** |
| 3 | 2 | 0 | **2** |
| 4 | 4 | 12 | **16** |
| 5 | 2 | 3 | **5** |
| 6 | 9 | 10 | **19** |
| 7 | 3 | 8 | **11** |
| 8 | 8 | 13 | **21** |
| 9 | 6 | 15 | **21** |
| 10 | - | - | **-** |
| 11 | 16 | 10 | **26** |
| **Total Visits** | **52** | **73** | **125** |

Table 1 – Visits to Centre in Autumn Term 2007/2008

| Total Number of Visits made by Individual Students | Student Year | | Total |
|---|---|---|---|
| | Year 2 | Year 3 | |
| Only 1 visit | 6 | 19 | **25** |
| 2 visits | 4 | 4 | **8** |
| 3 to 5 visits | 5 | 6 | **11** |
| 6 or more visits | 2 | 2 | **4** |
| **Total** | **17** | **31** | **48** |

Table 2 – Number of visits made by individual students

The data in Table 1 & 2 simply show patterns of usage by students, but we sought to better understand just how and why the students were making use of this resource. To assist with identifying this, observations of students using the room were carried out to determine how students were using the centre, and, as a follow-up, several structured interviews with student users were conducted. Observations started in the later weeks of the term when more students were using the centre. Seven observation sessions of between two and four hours were undertaken in Weeks 8-11. The results were not entirely surprising given how it was intended the centre should be used:

- many students attend the centre in groups to work informally on coursework problems; peer support within these groups is often clearly evident;
- students make use of the computing facilities to undertake computer-based coursework,
- students make use of the text-based resources available;
- students, in groups, use the projection facilities to prepare and practice their presentations;

The observations also showed that while some students use the centre as a general space, for checking emails and browsing the internet, these are very much in the minority. It was interesting to note that there were also a number of discussions held amongst students regarding aspects of their courses other than assessed work, and these were almost exclusively amongst students in Year 3. For example, there was discussion of aspects of their mathematics lectures, and discussions about their choice of course module and options.

Students in the Centre Making Use of the Presentation Facilities

Interviews with four students confirmed the observations of how the room was being used. It appears that the primary motivation for using the centre is to undertake coursework and try to improve their grades. There was little evidence that students were working to develop deeper understanding of mathematical concepts and ideas:

***H - …for me grades is the main objective. Obviously I'd like to have understanding of it [as] I wouldn't have to do as much revision as I would if I didn't [understand it].***

Students were asked whether they tended to use the centre for individual study or for group work, and it appears students are happy to use the facility for both purposes, but the importance of peer support was clearly emphasised echoing the findings of the pre-action phase:

> ***E - …,I think if you get stuck on things, it's nice to have somebody else, people to bounce off ideas, and also you know if you need help and you can't get anyone in the other [Support Centre] room, then you've got someone else to ask….***

> ***H - …we often do the same problems at the same time, sort of a competitive thing and then at the end of it see who's got the right answer and if we get different answers, we discuss them and have a look at each others work and see if we can see if they went wrong somewhere.***

When students work in groups in the centre, they often arrive in 'pre-formed' groups and know those they work with well. There was no evidence of peer groups being developed solely as a result of using the centre which is perhaps not surprising, but one student realised it was important to move beyond individual study:

> ***E - …I think I was in my room mostly, because I only started venturing out my room last year to do work, when I realised it wasn't really working…***

One emerging finding regarding the fact that no staff are 'on hand' to assist students indicates that the students do not mind this:

> ***H - …I don't think they [a member of staff] should pop in, otherwise people will be dependent on waiting for them to come in…***

This validates the idea of using such centres to encourage students to become independent learners. However, it should be noted that the close proximity of appropriate members of staff to the centre means that students are able to approach staff quickly and easily even though they are not directly available within the centre. This is a factor that was identified as being important to student attitudes and motivation within [4].

## Conclusions

This article has provided a rationale for extending the model of mathematics support from one of remedial provision to one of enhancement. The rationale has drawn upon research evidence gathered by mathematics educators during several studies of the undergraduate mathematics experience, on recent recommendations from the National Audit Office report on student retention [10] and on data from focus groups conducted within Loughborough University. We have described the establishment of a facility for specialist mathematicians which is intended to improve their resource base, improve their engagement and develop positively their identities as members of a community of mathematicians. While this approach is still in its very early stages, it is clear that its impact upon students is positive. Peer support appears to have a significant role in student motivation and confidence, and its impact upon student achievement and encouraging further study is one that we intend to investigate further as part of a programme of activity in this area. We invite and welcome comments and suggestions that may help shape developments during the next cycle of activity.

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# A23. Increasing the Supply of Mathematical Sciences Graduates A Community-wide Programme of Activity

**<u>Grove, M.J.</u>** & Lawson, D.A. (2006). Increasing the Supply of Mathematical Sciences Graduates A Community-wide Programme of Activity. *MSOR Connections*, 6(4), pp. 3-8.

Michael Grove and Duncan Lawson

# Increasing the Supply of Mathematical Sciences Graduates

A Community-wide Programme of Activity

Michael J. Grove
Maths, Stats & OR Network
School of Mathematics, University of Birmingham
m.j.grove@bham.ac.uk

Duncan A. Lawson
Faculty of Engineering & Computing
Coventry University
d.lawson@coventry.ac.uk

In August 2006 the Higher Education Funding Council for England (HEFCE) approved funding for a £3.3 million pilot programme of activity designed to increase and widen participation within the mathematical sciences. The moremathsgrads proposal was developed by the Heads of Departments of Mathematical Sciences (HoDoMS), the Institute of Mathematics and its Applications (IMA), the London Mathematical Society (LMS), the Maths, Stats & OR Network, and the Royal Statistical Society (RSS) and followed a period of community-wide consultation [1]. Many national organisations have given their support to the Project and, to date, 22 individual HEIs have expressed a desire to be directly involved in its activities.

Within this paper, we will present evidence gathered during the development of the project proposal thereby providing an overview of the current situation in the mathematical sciences; we will review the aims and objectives of the project; and conclude by outlining the activities that will take place throughout the pilot phase of activity.

## Evidence of a Decline

Mathematics is a compulsory part of the National Curriculum for all Key Stages. This can be a double-edged sword in terms of increasing the popularity of mathematics. On the one hand, it means that all school students have to continue to study mathematics until age sixteen. But, on the other hand, this can have a negative effect as many students perceive mathematics to be hard, boring, and not relevant to their future and not leading to employment. Furthermore, whilst many students find mathematics hard, there is clear evidence that the current curriculum fails to stretch and inspire the more able students [2].

Although many disciplines in Higher Education (HE) either require or prefer A-level mathematics as an admission qualification, the number of entries to A-level mathematics has shrunk from nearly 85,000 in 1989 to around 53,000 in 2004. This decline has occurred at a time when the total number of A-level entries has increased significantly, and so consequently the percentage of mathematics entries compared to the total A-level entries has fallen over this time from 12.8% to 6.9% [3].

A recent report by the Qualifications and Curriculum Authority (QCA) [4] noted that around 50% of the GCSE cohort achieve grades A* to C, a figure of approximately 300,000, in 2004. However, only around 63,000 of these students went on to take AS level in mathematics, and, of these, only 41,500 sat the A-level. In other words, only 14% of those achieving GCSE grades A* to C in mathematics go on to take an A level in the subject.

This decline in the popularity of mathematics has important implications for other subjects in Science and Technology as mathematics underpins disciplines such as Engineering, Physics and Chemistry. Indeed, those involved in the teaching of Physics and Engineering within HE have spoken of a 'mathematics problem' for some time, particularly at the transition to university study [5], [6].

Data obtained from the Higher Education Statistics Agency (HESA) shows that the overall number of full-time UK and EU starters studying the mathematical sciences has fallen from 9196 in 1998 to 7985 in 2004, a drop of approximately 13%. The decline is also evidenced by the 2005 HEFCE report of the Chief Executive's Advisory Group on Strategically Important and Vulnerable Subjects [7] which noted a fall in activity of 9.3%, or 1800 FTEs, as measured from 1999-2000 to 2003-2004. It should be noted that there has been considerable confusion surrounding the number of undergraduates within the mathematical sciences over the last few years. This uncertainty has arisen as a result of changes to the coding system used by HESA in 2002-2003. A recent study by the LMS [8] has identified these anomalies, and confirms that the number of students studying programmes within the mathematical sciences has fallen significantly over recent times.

## Breadth of Student Participation within the Mathematical Sciences

Whilst the statistics outlined in the previous section indicate that the mathematical sciences have become generally less popular subjects in the student population as a whole than many other subjects, there are particular student groups where this unpopularity is even more marked.

The recent QCA report on participation in mathematics at A-level [4] notes that: 'there is less success in recruiting girls to AS and A-level mathematics than boys'. An analysis of the HESA data confirms this continues at undergraduate level. In 2003-2004 the proportion of females in the mathematical sciences was 38%, similar to the figure in 1999-2000. This compares unfavourably to the overall gender balance whereby the HE student population is approximately 58% female.

There are also considerable differences in the participation rate by ethnic origin as illustrated by the HESA data in Table 1.

| Ethnicity | Total students | White | Asian (inc. Chinese) | Black | Other | Unknown |
|---|---|---|---|---|---|---|
| Maths | 7985 | 74.8 | 14.5 | 3 | 2.9 | 4.8 |
| Total HE | 342769 | 77.0 | 9.8 | 4.6 | 3.2 | 5.4 |

**Table 1 – Percentages of different ethnic groups for full-time UK and EU starters in 2004**

Participation can be seen to be lower for both the Black and White ethnic groups, but higher for Asian groups; this is due to the high popularity of the mathematical sciences amongst Chinese and Indian students. The ethnicity distribution has remained stable from 1998 to 2004, despite the number of full-time UK and EU starters decreasing by 13% over the same period.

A report published by the Royal Society [9] in April 2005 investigated the attainment of pupils at different stages in mathematics. This showed clear differences in level of performance of different ethnic groups. For example, in 2002, 67% of the 600,398 eligible pupils achieved level 5 or above at Key Stage 3 in Mathematics. For the 498,614 students from White ethnic groups 68% achieved level 5 and above, but for students who are from the Black Caribbean (8040), Black African (7003), Pakistani (13,713) and Bangladeshi (5,141) ethnic groups the percentages were 52% or lower. Chinese (1,962) and Indian (13,949) students had much higher percentages at 87% and 74% respectively.

The HESA data show that the students studying the mathematical sciences full-time tend to be younger than the average for students on all subjects. Some students progress through school mathematical examinations at a fast pace and so enter higher education at an earlier age. At the other end of the age range, however, the numbers of older students studying the mathematical sciences are relatively low when compared to the total HE population. This is shown in Table 2.

| Ages | Total FT students | Under 18/ Unknown | 18-21 | 22-30 | 31+ |
|---|---|---|---|---|---|
| Maths | 7985 | 4.1 | 85.7 | 6.1 | 4.1 |
| Total | 342769 | 2.6 | 78.7 | 12.5 | 6.2 |

**Table 2 – Percentages of full-time UK and EU starters by age group in 2004**

The situation has remained relatively constant with respect to age group throughout the period 1998-2004, with the exception of a small decline since 1998 of the proportion aged 22 and over (down to 10.2% from 11.4%). Participation within the mathematical sciences for those over the age of 22 (10.2%) is considerably lower than the average for HE in general (18.7%).

Carrying out a similar analysis on the data for part-time students shows that the age distribution of this group of learners aligns closely with the age distribution of all part-time students (Table 3):

| Ages | Total FT students | Under 18/ Unknown | 18-21 | 22-30 | 31+ |
|---|---|---|---|---|---|
| Maths | 961 | 1.1 | 8.3 | 35.5 | 55.0 |
| Total | 60770 | 0.5 | 9.7 | 33.5 | 56.3 |

**Table 3 – Percentages of part-time UK and EU starters by age group in 2004**

Comparison of the data in Tables 2 and 3 shows that only 1.6% of part-time students study the mathematical sciences compared to 2.3% of the full-time cohort.

Analysis of the HESA data by socio-economic classification shows the profile of entrants to full-time degrees in the mathematical sciences to be heavily weighted towards the higher socio-economic classifications, with less that 25% of students in groups 4-7.

In summary, the mathematical sciences appear to be particularly unpopular with female students, with certain ethnic groups, with mature learners, with part-time students and with those from certain socio-economic groups. There is therefore considerable potential to increase enrolments in the mathematical sciences in higher education from these groups.

## The Aim of the moremathsgrads Initiative

The moremathsgrads initiative aims not only to increase the number of undergraduates studying the mathematical sciences in England, a need clearly identified, but also to widen participation from groups of learners who have not traditionally been well represented in Higher Education. If there is success in widening participation in the mathematical sciences in Higher Education, then it follows that there will also be success in increasing the number of mathematical sciences graduates; the two aims of the Project are intrinsically linked.

The project will therefore seek to: address the gender imbalance that currently exists in the mathematical sciences; encourage more students from the Black African, Black Caribbean, Pakistani and Bangladeshi groups to study the mathematical sciences; encourage more returning adult learners, particular those studying part-time to choose the mathematical sciences; and, to increase the number of learners from the lower socio-economic groups.

In addition to increasing the number of mathematical sciences graduates, the project will also have an impact in other important areas that will be of real benefit for society, for example:

- Increasing the number of students taking mathematics at A-level (or an alternative level 3 qualification), particularly amongst students who have not achieved the highest grades at GCSE.
- Increasing the mathematical achievement of students who may decide to study other STEM related programmes within HE.
- Increasing the number of specialist mathematics teachers in schools by increasing the number of undergraduate students who wish to train as teachers.

In order to meet its overall aims, the Project has four objectives and these may be conveniently expressed as four themes. The themes contain aspects of support for school and college students to gain, and then sustain, their interest in the mathematical sciences and to encourage them to pursue their further study within higher education:

1. **Careers Theme:** Improve understanding of the wide-ranging applicability of mathematics and the breadth of career opportunities open to graduates from the mathematical sciences.
2. **Student Theme:** Help school and college students to understand the purpose of mathematical study, to enjoy mathematics, to be confident about meeting challenges in the subject, to realise their potential in mathematics and to raise their aspirations about further study of mathematics.
3. **Teaching Theme:** Contribute to the development of teachers' enjoyment, confidence and knowledge of mathematics and its applications so that they can help stimulate interest in further study of mathematics in their students.
4. **HE Curriculum Theme:** Increase the scope of the mathematics curriculum for HE nationally in order to allow real choices for a wide range of students.

## The Implementation of the moremathsgrads Initiative

The activities of the moremathsgrads project will take place within three regions for an initial period of three years: the West Midlands, Yorkshire and Humberside, and London. Three lead universities are involved from each region, and these are Coventry University, the University of Leeds, Queen Mary, University of London. Sheffield-Hallam University will lead the HE Curriculum Development theme. The project will work with 7 schools and colleges within each region; these institutions will be chosen based upon widening participation criteria in consultation with Aimhigher and Action on Access.

Strategic advice and guidance to the Project, along with responsibility for the management of its day-to-day activities will be provided by the Maths, Stats & OR Network at the University of Birmingham.

The Project will develop and expand links between schools, colleges, careers organisations, universities and employers. Engagement with regional and national employers is therefore crucial if the project is to succeed. Four major employers have already expressed their support and commitment to this proposal: Rolls-Royce PLC, Thales, Qinetiq and the Ford Motor Company. In addition, further employers will be identified via the networks of the organisations involved in the development of this proposal, along with HE alumni networks, the Sector Skills Councils and local SETPOINTs.

## The Careers Theme Explained

There is substantial evidence that shows that when students are making their choices with regard to A-levels and university study they are not aware of the types of careers that follow from studying the mathematical sciences [4], or indeed of where mathematics is used within the workplace [10]. In addition, there is anecdotal evidence that there is a lack of understanding on the part of teachers and careers advisors of the range of careers available in industry and commerce for people with a mathematical sciences degree. This view was confirmed during discussions with several teachers during the consultation phase of the proposal development.

While there may be little understanding of the range of careers available in industry and commerce for people with a mathematical sciences degree, employment prospects for mathematical sciences graduates are very good, particularly for students with wider skills who can communicate mathematical ideas and concepts to non-mathematical people. A study at the University of Newcastle, reported in the Times Education Supplement [11], compared the incomes and educational backgrounds of 4,500 people and concluded that having a Mathematics A-level can increase long-term earning power by 7 to 10 per cent.

The moremathsgrads initiative will develop a series of high quality careers resources for use by students, teachers and careers advisors, promoting the diverse range of employment opportunities open to graduates from the mathematical sciences. Employers and universities will have direct input into the creation of these materials. The resources will be made available nationally on the Council for Mathematical Sciences (CMS) www.mathscareers.org.uk website, which will also undergo extensive redevelopment as part of the project. In addition, careers events within pilot schools and colleges and regional careers fairs featuring talks and exhibits by employers will be offered to students. These careers events will be aimed at those students taking GCSE or AS/A-level mathematics and will provide an opportunity for greater engagement between students and those using mathematics in the workplace.

To ensure students receive comprehensive and accurate careers advice, the moremathsgrads initiative will engage directly with careers advisors and teachers. The Project will run yearly training events, and will work with national careers organisations, including Connexions, to share the resources produced and improve the standard of careers advice that students currently receive with regard to the mathematical sciences.

The approach proposed builds upon the recommendations from a National Institute for Careers Education and Counselling (NICEC) report [12] on choosing science at age-16. The moremathsgrads initiative will: strengthen the links between mathematics departments and careers departments and their advisors; offer events designed to stimulate interest and to inform students about mathematics while they are still in school; and offer opportunities for students to have contact with holders of some higher-level jobs relating to mathematics, or those who have studied mathematics.

## The Student and Teaching Themes Explained

The student and teaching themes are intrinsically linked, and so here we choose to discuss them together. Whilst the student theme addresses current students, in order to achieve long term embedding and sustainability of key elements of the Project, it is necessary to engage teachers fully with these elements. This will enable teachers to become more effective in promoting the mathematical sciences to their students. Indeed, a justification of this approach is highlighted by the Ofsted report on Secondary education published in 1998 [13], which commented:

'When teachers are thoroughly in command of their subject, they are able to adapt their teaching to the responses of the pupils, to use alternative and more imaginative ways of explaining, and to make connections between aspects of their subject and with pupils' wider experiences, so capturing their attention and interest. The teacher's ability to answer spontaneous questions is an important factor in generating enthusiasm for the subject.'

Clearly there will be a degree of overlap with the remit of the recently established National Centre of Excellence in the Teaching of Mathematics (NCETM), particularly in the nature of the support offered to teachers. The project will support, and provide access to, the work of the NCETM in developing both the subject and pedagogical knowledge of teachers of mathematics.

The Project will offer a series of enrichment and enhancement events to students within the pilot regions; the aim of which is to enthuse and inspire. The format of such events will be based upon the successful Royal Institution Masterclass series, and will be primarily facilitated by members of university mathematical sciences departments, although teachers will be encouraged to offer similar events themselves. The resources developed to run the enrichment and enhancement classes will all be made available on the Project website, www.moremathsgrads.org.uk, for use by those running similar events nationally. Larger events will be offered for both students and teachers within universities demonstrating 'real world' applications of mathematics.

Undergraduate students will be engaged to assist teachers within local schools, and this forms an expansion of the successful ambassador type schemes that are already available. The Project will also work to promote the range of provision available to adult learners, such as the Open University Mathematics modules, to enable them to study the mathematical sciences within higher education.

## The HE Curriculum Development Theme Explained

The HE Curriculum Theme will have a number of strands of activity. In one strand, it will address issues of breadth of provision and its attractiveness to a wide range of potential learners. It is important to understand why mathematics is unpopular amongst certain groups of students. For example, work in this theme will explore whether the types of courses and mode of study available in the mathematical sciences (rather than the subject itself) act as a disincentive to mature or part-time students.

Another strand will be to explore the learning, teaching and assessment methods in university mathematical sciences departments to determine if changes might be made to better support students throughout their studies. In recent years, many universities have made significant investment in support provision [14] particularly aimed at non-specialist students. However, there is emerging evidence that points to a problem amongst specialist mathematical sciences students during the later years of their programmes [15]. One way to increase the number of mathematical sciences graduates is to increase the success rates of those that are currently recruited and so work in this area will contribute directly to the achievement of the project's principal aim.

A further element of work in this theme will address the issue of 'graduate skills' within the undergraduate cohort [16]. Notwithstanding the key fact that, from the employers point of view, the mathematical sciences are a highly desirable discipline, it is nonetheless important to ensure that graduates have the appropriate generic skills that employers want in addition to the special skills that mathematical sciences graduates bring.

Activities within the HE Curriculum Development Theme will not be restricted to the regional partner institutions but will involve other mathematical sciences departments throughout the country that are keen to explore this crucial element of increasing the attractiveness of the mathematical sciences in higher education.

## Conclusions

The activities to be undertaken as part of the moremathsgrads initiative have been designed to produce the following key outcomes:

- A positive change in the perception of mathematics amongst school students and in the way in which schools engage with HE and the mathematical sciences.
- An improved understanding of the pathways available for students who wish to study the mathematical sciences in HE.
- A greater awareness and understanding of the applications and opportunities offered by a study of the mathematical sciences.

These will lead to:

- More HE students within the mathematical sciences;
- More HE students within the mathematical sciences who are women, students from the lower socio-economic groups, minority ethnic students and adult learners;
- More students who are women, students from the lower socio-economic groups, minority ethnic students and adult learners enrolled upon HE courses with a significant mathematical component, for example, Economics, Physics and Engineering;

Monitoring and evaluation will form an ongoing process throughout, and activities, events and resources will be developed and tailored in response to this process. The moremathsgrads Project will run until July 2009, and regional activities will commence in Spring 2007.

Although activities are focussed within three regions, it should be stressed that any resources produced by the Project will be made available nationally on the two Project websites: www.moremathsgrads.org.uk and www.mathscareers.org.uk.

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# A24. A Response to the Royal Society paper: Science Higher Education in 2015 and beyond – call for evidence

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Stephen Hibberd and Michael Grove

# A Response to the Royal Society paper: Science Higher Education in 2015 and beyond – call for evidence

Stephen Hibberd
School of Mathematical Sciences
University of Nottingham
stephen.hibberd@nottingham.ac.uk

HE Academy Maths Stats & OR Network – Graduate Skills Working Group
(Stephen Hibberd, Chair of Group, University of Nottingham
Michael Grove, MSOR Network Manager - University of Birmingham)

Michael Grove
Network Manager – MSOR
University of Birmingham
m.j.grove@bham.ac.uk

This submission addresses directly the identified issue:

***"increasing employer and other requirements for subject specific knowledge, relevant experience in a workplace, and generic skill assimilation within first degree courses."***

## 1. Graduate skills in mathematics

There is well-documented expectation from Government, employers and students that undergraduate and postgraduate courses should provide graduates with enhanced skills and attributes for future economic and other benefits. In particular, the Robert's Report 'SET for Success' [1], highlights serious implications for UK Science and Engineering:

***"graduates and postgraduates in these strongly numerical subjects are in increasing demand in the economy – to work in R&D, but also to work in other sectors (such as financial services or ICT) where there is a strong demand for their skills."***

There is an increasing realisation within a digitally connected and enhanced world of the importance of enhanced specialist skills from mathematics graduates, and that mathematical training within Engineering and Science is needed for a shift to a higher level of innovation in R&D. The Smith Report [2] presented a number of difficulties faced by employers in recruiting appropriately qualified scientists. Within the report Smith concluded that the current (School) curriculum and qualifications framework ***'fails to meet the mathematical requirements of learners, fails to meet the needs and expectations of higher education and employers and fails to motivate and encourage sufficient numbers of young people to continue with the study of mathematics post-16'***. A key requirement from any form of initiatives is to ensure that such comments cannot be aimed at the HE – MSOR provision. Clearly to attain this aim will require co-ordinated action from the Government, employers, universities and the HE mathematics community and professional organisations.

Recent Government led responses include the publication of a long-term strategy [3] that includes a proposal to increase the number of young people taking A-levels in mathematics by about 10,000 entries per annum by 2014. Further, a community-wide mathematics proposal has been formulated to increase the supply of Mathematical Science Graduates [4]. These initiatives are tangible recognition that employment demand for mathematically capable graduates is perceived as widely applicable throughout industry, business, commerce and the public and private sectors [5]. In 2004, 61% of mathematics graduates had entered employment in over 18 work sectors [6]. The QAA Benchmarking statement [7] highlights that

| | |
|---|---|
| **Marketing, Sales and Advertising Professionals** | **2.9%** |
| **Commercial, Industrial and Public Sector Managers** | **9.0%** |
| **Engineering Professionals** | **1.2%** |
| **Education Professionals** | **12.0%** |
| **Business and Financial Professionals and Associate Professionals** | **28.8%** |
| **Information Technology Professionals** | **5.4%** |
| **Other Professionals, Associate Professional and Technical Occupations** | **2.7%** |
| **Numerical Clerks and Cashiers** | **9.9%** |
| **Other Clerical and Secretarial Occupations** | **11.7%** |

**Table 1 – Main careers undertaken by mathematics graduates 2004 (% of all work) – from [6]**

MSOR graduates possess knowledge and skills that will enable them to make a contribution beyond other subject areas particularly where a combination of analytic, numerical and communication skills is valued. Additionally many maths graduates can diversify further through postgraduate study, either into research in universities or advanced courses towards specialist employment opportunities within many industrial and commercial sectors. In 2004, 24% of all maths graduates went into further study and another 11% combined both employment with study [7]. Case studies of MSOR graduates entering a diverse range of jobs are readily available through websites [8] and [9] aimed at informing pre-university, undergraduate and graduate sectors; these confirm the good career enhancement and personal satisfaction that can be obtained. The areas of work entered by graduates are identified within Table 1, with some 40% entering traditional areas of Business, Finance and numerate areas such as Accountancy, but also a great diversity of other employment areas.

## 2. A strategic case for graduate skills enhancement

Within a strategic review of STEM subjects [10], mathematics is recorded as having a substantial base of 17,000 FTEs in 2003-4 but identifying a prior period fall of 9.3%, which is of concern. An underlying vulnerability has been identified for mathematics and the reality of possible impact on other subjects would be significant. The report identified vulnerability as having a possible mismatch between either of the two or more parts as illustrated in Figure 1.

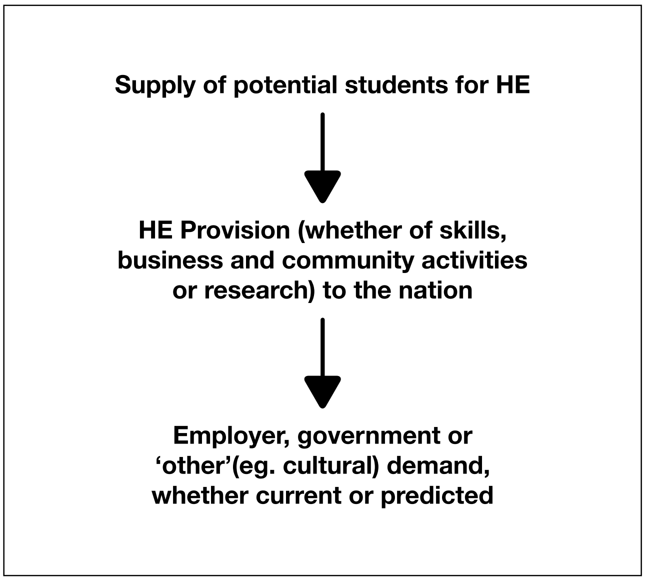



**Fig 1 – Illustration of areas of vulnerability- see [10]**

***"There is an ongoing need for academic staff and employers to understand and integrate the skills that are, and could be, developed during the learning process for mathematics and statistics."***

A welcome response is HEFCE funding for the proposal to increase the supply of students to the Mathematical Sciences [4], however to obtain full benefit, other downstream aspects will need to be implemented from within HE through greater attention to skills acquisition for graduates and greater interaction between HE and employers.

HE is coming under increasing pressure that graduates should possess enhanced skills alongside a strong tradition of provision in knowledge and understanding, indeed the Robert's report [1] notes:

> ***"Furthermore, there are mismatches between the skills of graduates and postgraduates and the skills required by employers (for example, many have difficulty in applying their technical knowledge in a practical environment and are seen to lack strong transferable skills)".***

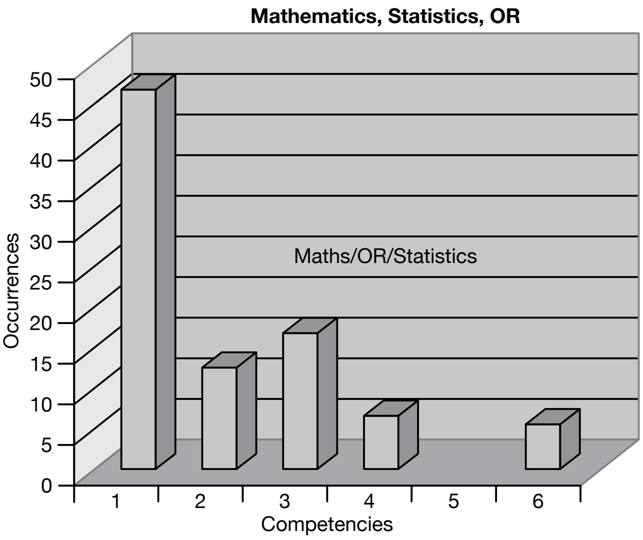
Explicit recognition of the importance of skills development within undergraduate programmes is explicitly included in the latest QAA specifications [11] which propose that specifications should be written to provide a source of information for, amongst others,

> ***"Employers, particularly about the skills and other transferable intellectual abilities developed by the programme".***

Further, guidance suggests learning outcomes

> ***"should be linked directly to the knowledge, understanding, skills capabilities and values that a student will have gained after completing a programme".***

The Benchmark Statement for MSOR is very upbeat on the topic of career opportunities for mathematics graduates however there remains a significant lack of detailed study and claims are not readily justifiable in all programmes. A recent project on enhancement of student employability skills is provided by ESECT and the HE Academy [12] that has been ongoing since 2002. One outcome was the creation of a 'Student Employability Profile'[13], based on a competencies analysis of the QAA Benchmark Statement. Such data was also reproduced in more graphic style, as shown in Figure 2, in a recent guide to employers [14].




| | |
|---|---|
| **1** | Cognitive Skills:<br>analysis, judgement, attention to detail |
| **2** | Generic Competencies:<br>high level transferable skills |
| **3** | Personal Capabilities:<br>life long learner, self-starter, finish the job |
| **4** | Technical Ability:<br>ability to apply and exploit modern technology |
| **5** | Business and/or Organisational Awareness:<br>appreciation of how business operates, work experience, organisational culture, basic financial and commercial principles |
| **6** | Practical and Professional Elements:<br>critical evaluation of professional practice, reflecting and reviewing own practice on an ongoing basis |

**Figure 2 – Plot of competencies evaluated in Mathematics- see [14]**

Even a cursory inspection will identify a traditional overwhelming emphasis on cognitive skills (with strong emphasis on knowledge and understanding) with more limited attention to other competencies. This imbalance is also highlighted by the availability, for the first time, of additional post-graduation data collected by HESA and displayed on the HERO website [15] to provide detailed information for prospective undergraduates and employers. For 2005 this identifies mathematics graduates as the least satisfied over all subjects in terms of personal development (based on responses to: helped me to present myself with confidence; my communications skills have improved; I feel confident in tackling unfamiliar problems). The overall satisfaction of graduates in mathematics, however, is high.

## 3. Integrative learning for the next decade

Mathematics should be well placed to articulate and provide information to employers and prospective students of the relevance, wide skills base and skills attainment that can be gained from within the wide range of the 1496 courses within 95 UK Universities [16]. Potential skills, intrinsically embedded within a Maths degree and relevant to an extensive range of employment areas include:

- Analytical, modelling and logical problem solving skills;
- Ability to evaluate, analyse and interpret numerate information;
- Apply transfer knowledge from one situation to another;
- Ability to learn for oneself; be a self-starter and a finisher;
- Highly developed skills of numeracy, permitting accurate and informed manipulation of numerate concepts;
- Gained general and specialist ICT skills;
- Ability and readiness to address new and related problems.

Increasingly students are looking for high employability prospects upon graduation. The areas of employment (careers) and employability skills are not sufficiently recognised or acknowledged, partly perhaps as many MSOR graduates move seamlessly into multi-disciplinary teams. There is an ongoing need for academic staff and employers to understand and integrate the skills that are, and could be, developed during the learning process for mathematics and statistics. This may involve more innovative individual or group based project activities, vocationally orientated experiences, interdisciplinary seminars and case studies. Personal attainment can be identified through peer-assessment, reflective logs and personal development portfolios. Such skills are also extremely beneficial and relevant to those going into advanced study or university-led research. A number of initiatives are underway and good practice does exist within the MSOR community in pedagogic development, innovation and implementation. The HE-Academy Working Group has been established to identify and help coordinate individual initiatives but also related activity is ongoing within the newly established CETLs (e.g. [17], [18]) and individual Institutions (e.g. [19]).

## 4. Conclusions

Graduate skills attainable within MSOR need to be evidenced by appropriate attention to the curriculum and structure of degree programmes. There is a compelling case to identify, articulate, develop and record the core general and subject-specific skills proficiencies, but also to include achievement outside of the traditional taught discipline aspects. Provision might include extensive and innovative project work, vocationally related experiences (e.g. UAS), Study Abroad experiences and also mechanisms for the inclusion of placement or voluntary work as credit bearing elements. A more integrative approach has the potential to enhance student's motivation, their academic performance, their employability in a global market and their confidence to engage successfully with the challenges and expectations of a rapidly changing world.

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18. Centre for Integrative Learning, University of Nottingham.
19. Centre for Education and Industry, University of Warwick.


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# A25. Mathematics Support - Support for the specialist mathematician and the more able student

Croft, A.C. & **Grove, M.J.** (2006). Mathematics Support - Support for the specialist mathematician and the more able student. *MSOR Connections*, 6(2), pp. 1-5.

# Mathematics Support

## Support for the specialist mathematician and the more able student

**Tony Croft**
**Loughborough University**

a.c.croft@lboro.ac.uk

**Michael Grove**
**University of Birmingham**

m.j.grove@bham.ac.uk

In the recent past, measures have been put in place nationally to ensure that all students embarking upon undergraduate programmes with a strong mathematical content have access to resources that will ease their transition into higher education. Universities have taken a variety of steps to ease any problems at the school/higher education interface. Substantial effort is going into initiatives designed to encourage more school students to study mathematics in the post-compulsory sector and to improve the quality and preparedness of those that do.

However, evidence recently published refers to some problems emerging in later years, particularly year 2 of single honours mathematics programmes, with disillusionment amongst parts of the cohort and high drop-out rates, at least in some institutions. This ought to concern the mathematics community because, whereas the more widely reported 'mathematics problem' was largely concerned with non-specialist 'users' of mathematics (e.g. engineers), the groups under consideration here self-select to study mathematics at university. Furthermore, some of those who do succeed in HE are not well-prepared for postgraduate study. Concerns have been raised at the highest levels about the number and quality of 'home-grown' entrants to mathematics PhD programmes and these have long-term effects for the UK science base.

This paper will briefly review mathematics support at the transition. It will then pose questions about the ways in which support might be developed so that undergraduate mathematicians in their second and third years might be better supported and encouraged to become even more confident, competent and independent learners. It will suggest work designed to improve the preparedness of those students who might consider postgraduate research in mathematics. The role of the Higher Education Academy Maths, Stats & OR Network, and other bodies with national influence such as *Sigma* – the Centre for Excellence in Mathematics & Statistics Support, is discussed with a view to opening a constructive discussion about what the community as a whole can do to enhance the learning experience of these students.

### *1 The challenge at the transition*

The mathematics higher education community is well aware of the challenges facing those who teach mathematics to both specialist mathematics students (those who come to university to study single and joint honours mathematics programmes) and non-specialist 'users', such as engineers and physical scientists. Increasingly, other groups (e.g. nursing tutors) are also finding that their students neither possess the requisite mathematical skills nor are keen to acquire them.

We won't go over old ground here, but those who are not familiar with the difficulties which have emerged over the past 15 years or so should consult the many research papers or reports from learned societies and professional bodies listed in references [1...9].

The higher education mathematics community has responded enthusiastically to the challenges at the transition (see Appendix I for a list of several of the many initiatives). Government, somewhat belatedly, and following lobbying by the professional bodies, learned societies and individuals, has acted and set in place initiatives to improve both mathematics teaching in schools and the supply and quality of students who want, and are qualified, to study mathematics in the post-compulsory sector. Universities are tackling transitional problems through, for example, provision of summer schools, and bridging mathematics courses. An overview has been published by the LTSN MathsTEAM project (http://mathstore.ac.uk/mathsteam). Another approach is through support centres which many universities have now established. Perkin & Croft [10] provide a review of provision nationally and the MSOR Network has published the guide *Good Practice in the Provision of Mathematics Support Centres* [11]. Universities now have access to a range of quality resources e.g. the Subject Centres of the Higher Education Academy, the FDTL4 project *Mathematics Support at the Transition to University* which has developed **math**tutor[1], the FDTL4 project *Helping Engineers Learn Mathematics*[2] (HELM), and the **math**centre[3] project. There are also substantial resources available from earlier projects although increasingly, it has not been possible to upgrade these to run on modern operating systems. Initiatives exist to increase the supply of mathematically-capable school leavers, e.g. the National Further Mathematics Network[4], the National Academy for Gifted & Talented Youth[5], and the Millennium Maths Project[5a]. The new National Centre for Excellence in Teaching Mathematics[6] has a remit which includes developing CPD for teachers. Effects of these have yet to feed through into the HE system.

### *2 Emerging issues*

While it would be untrue to say that the problem at the transition has been solved, it is the case that (a) an ample supply of free, good quality resources are available to help any students serious about remedying their shortcomings, and to help academic and support staff who aspire to assist students who struggle at the school/ university interface, (b) a significant proportion of universities have invested substantially to put palliative mechanisms in place (e.g. support centres), and (c) there are several high profile, well-resourced national projects designed to increase the supply of mathematically qualified school leavers, and to improve teaching quality and continuing professional development of mathematics teachers.

However the 'mathematics problem' has several other dimensions. One is the 'mechanics problem' highlighted by Robinson, Harrison & Lee [12]. There are others - and these impact upon the specialist mathematics community rather than non-specialist users of mathematics.

Firstly, in 2002 Brown et al. [13] published work in respect of *Student Experiences of Undergraduate Mathematics* arising from a three year ESRC funded project that examined progress and attitudes of single honours mathematics undergraduates in two research-led universities. Their report notes *"for many of those staying* [on the course] *attainment was average and below, the problems of coping with the work were accompanied by growing disillusionment with mathematics; generally, although with some exceptions, students enjoyment of the subject declined over time".* Many did not adapt well to develop new styles of working in order to cope at University. *"Such students became mildly depressed in the second year and seemed to lack immediate sources of support and the motivation to seek these out".* The research investigated failing second year students. From the same study, Macrae et al. [14] write: *"it is difficult to know what more the university could do to support these struggling students especially as they tend to withdraw when faced with lack of success and many find it difficult to talk openly and honestly about their situation. However, faced with widening participation, universities need to put in place increased support structures to encourage struggling [second year] students to seek help before it is too late".*

However, it should be noted that these findings are not ubiquitous. For example, Povey & Angier [15] cite very different experiences of students in their own institution. Their context though was different in that the students they researched were all on mathematics education courses and training to become secondary mathematics teachers. Their students' interaction with undergraduate mathematics was designed to be much more exploratory, negotiable, personal, social, supported and collaborative – and as they note, in clear contrast to the mathematics delivered rather more traditionally. The students they describe, whilst starting from a relatively weak background, went on to succeed. This is an important point, given the dire shortage of mathematics teachers in schools. It would be tragic if many of those students on single honours mathematics courses who might make good teachers are turned off the subject because of the way it is delivered in higher education.

Secondly, concerns have been expressed about the quality and numbers of UK PhD entrants in the mathematical sciences and cognate disciplines. The Review SET for Success [4] draws attention to the quality of PhD entrants to Science, Engineering and Technology departments:

*"A particular concern of many respondents to the Review was the quality of PhD students, both at the commencement of their study and on completion of it."*

It noted also that there had been a slight decline, from 1996-1999, in the proportion of PhD entrants in mathematics with a First or 2:1 degree. Over the same period there has been a slight increase in the proportion of such degrees awarded. (However, the Mathematical Sciences continue to attract the highest proportion, over 95%, of such students across the SET disciplines – this is quite different from the much lower proportions seen, for example, in Chemistry and Engineering). The Review did note that no firm conclusion should be drawn from their data in respect of mathematics.

The report *Where will the next generation of UK mathematicians come from?*, published by the Manchester Institute for Mathematical Sciences [16], notes:

*"the domestic supply of mathematically competent manpower is in such decline that in many areas (including... post-doctoral fellows and appointments to academic positions) we are now dependent on trawling recruits from other countries"*

and

*"In order to maintain the quality of postgraduate recruitment, public funds are increasingly being used to support students from other – mostly EU – countries."*

*"It becomes essential to ensure that our national curriculum and incentive structure allows our schools and universities to produce home-grown research mathematicians of sufficient calibre to compete with those from other countries."*

An international review of UK Research in Mathematics was undertaken in 2004 on behalf of the EPSRC and the Council for Mathematical Sciences (CMS) [17]. It comprised of 13 world-leading mathematicians and statisticians all based outside the UK. Amongst other issues, they were asked to comment upon the adequacy of the current three year PhD model prevalent in the UK.

*"The system of three-year PhDs can only work if there is excellent A level education at the school level. Our perception is that A levels are weaker than they used to be. The result then is that this produces many students who cannot compete with graduates from abroad."*

In 2005 HEFCE designated mathematics a *strategic and vulnerable subject* [18], recognition which can only help the discipline continue to secure additional government funding:

*"Mathematics has seen a fall in activity of 9.3% (1800 ftes, 1999/2000 - 2004/4). However total activity remained nearly 17500 in 2003-4 providing a substantial base on which to build."*

It is therefore incumbent upon the community to ensure that those students who we do manage to recruit are retained, motivated, well-served and in turn will help revitalise the discipline. It is these dimensions to the 'mathematics problem' that we suggest need to be explored further, and the Academy is keen to promote this view.

### *3 Supporting the specialist and the more able*

Given the scenarios painted in the previous section the questions that arise are concerned with:

- Improved pedagogies informed by existing research
- Extension of the role of existing support mechanisms
- Development of resources
- Professional development of academic staff
- New research, including into ways of developing independent learners
- Support of new mathematics postgraduates (not with teaching but with focussed research and study skills).

How can existing pedagogic research be used to improve practice? Can we understand better the identities of students who choose to learn mathematics? In what ways are they, and their learning styles, different from their predecessors and can we adapt our methods of teaching and their methods of learning in order to better achieve our objectives?

Much effort has been expended in developing support centres and other mechanisms at the transition. Can and should these be extended to offer support to students in later years? Is it sufficient to say that if these students cannot cope in year 2 then the problem is theirs not ours? What does this say about the current design of our programmes and our university admissions procedures?

Are there any resources which could be developed and made available nationally in order to help, at least, some of these students? Whilst it is obvious that specialisms increasingly emerge as students progress through the HE system, there may be a core of material which most students should be required to understand. Is there such a core and can resources be developed to support it?

There is undoubtedly a role for the professional development of academic staff. The gap between student performance and staff expectations continues to widen. The myriad of changes in schools and the increasing recruitment of staff from overseas means that many are unfamiliar with the UK education system and what it is delivering. How this professional development can be incorporated when staff have substantial, and very different, demands placed upon them will surely continue to be a source of tension.

There is a need for more pedagogic research intended to bring about positive change in the lecture theatre and the classroom. Too many students are disengaged from what is on offer now, but the community does not understand why, nor what can be done about it. Practice which is working well needs to be better disseminated and taken-up elsewhere.

Given these questions, what can the Higher Education Academy do to support all involved in the teaching, learning and assessment of mathematics specialists within Higher Education?

In order to help answer this question the Academy has established a dedicated website which is intended to promote discussion, and provide a forum for sharing of new ideas. To kick-start the process it is commissioning two mini-projects, each worth up to £5000 intended to address some of the issues outlined above.

The Call for Proposals can be found on the Network's website and the closing date is June 30th 2006.

### *4 Conclusions*

We have drawn attention to the fact that the 'mathematics problem', well documented since the 1990's now has manifestation beyond the transition to university. We have explained that the community has responded to transitional problems in many ways, but suggest that much more could be done to address issues emerging in later years. We have proposed a role for the Higher Education Academy MSOR Network and other bodies and hope we have opened this area up for a fruitful discussion about ways forward.

A website has been established (www.mathstore.ac.uk/lateryears) which will be used to collect and report upon the views of the higher education mathematics community, and which will seek, where appropriate, to respond to the challenges described here. We encourage all members of the community to share their views on the issues highlighted by visiting and contributing to the site.

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***Notes to article***

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[6] http://www.ncetm.org.uk

***Appendix I***

The following list of resources have either been developed specifically to support students making the transition to university in a subject with a significant mathematical component, or are appropriate for use by such students. All resources are available online, although those that have not been recently updated are marked [**Historical**]:

- CALM (Computer Aided Learning in Mathematics)
  http://www.calm.hw.ac.uk
  [**Historical**]
- CALMAT
  http://www.calmat.gcal.ac.uk
- Geomaths
  http://www.ucl.ac.uk/Mathematics/geomath/frontpage.html
  [**Historical**]
- HELM (Helping Engineers Learn Mathematics)
  http://helm.lboro.ac.uk
- **math**centre
  http://www.mathcentre.ac.uk
- **math**tutor
  http://www.mathtutor.ac.uk
- MathinSite
  http://mathinsite.bmth.ac.uk/
- mathwise
  http://www.bham.ac.uk/mathwise
- METRIC
  http://metric.ma.imperial.ac.uk
- School of Mathematics & Statistics, University of Plymouth
  http://www.plymouth.ac.uk/mathaid
- STARS (creation of STAtistical ResourceS from real datasets)
  http://www.stars.ac.uk
- STEPS (Statistical Education through Problem Solving)
  http://www.stats.gla.ac.uk/steps

# A26. The weakest link? Supporting the postgraduate teaching assistant

**Grove, M.J.**, Kyle, J. & Cox, W. (2006). The weakest link? Supporting the postgraduate teaching assistant. In D. Corcoran & S. Breen (Eds.), *Proceedings of second international science and mathematics education conference* (pp. 116–123). Dublin: St Patrick's College, Drumcondra, Dublin.

# Proceedings
# of
# Second International Science and Mathematics Education Conference

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## Theme: Interconnections between Science and Mathematics

## Editors: Dolores Corcoran & Sinéad Breen

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# THE WEAKEST LINK? SUPPORTING THE POSTGRADUATE TEACHING ASSISTANT

Michael Grove, Joe Kyle and Bill Cox
University of Birmingham

The themes for SMEC2006 pose two interesting and many-faceted questions: 'How essential is a good foundation in Mathematics for the teaching and learning of Science?' and 'How well do teaching methodologies translate between Science and Mathematics?' Yet who are the persons or communities to which these questions are addressed?
Within Higher Education, a major part is almost always undertaken by the Postgraduate Teaching Assistant, who all too often is regarded as the 'weakest link' in the system. Yet this is not the fault of the postgraduate student; it is indicative of the fact that this crucial role itself often receives very little attention, and the postgraduates themselves, even less support.
During this talk, we analyse the outcomes from a series of discipline-based workshops run by the Higher Education Academy Maths Stats & OR Network to support postgraduate students with teaching responsibilities. For the most part, these students had attended some form of generic institutional training, yet clearly felt the need for additional discipline-based development. In all 88 postgraduate students attended the workshops, and here we will present details of the typical teaching duties they identified they undertake (the results of which may be surprising), and the support that they felt they required. A measure of the success of the workshops is the high demand for further such meetings in the 2006-07 academic year.
Our presentation will conclude with suggestions and advice which will have direct relevance for anyone with an interest in supporting 'the weakest link'.

## Introduction

In October 2005 the Maths, Stats & OR (MSOR) Network, a Subject Centre of the United Kingdom Higher Education Academy, initiated a series of workshops for postgraduate students who teach Mathematics and Statistics in universities and other Higher Education (HE) institutions. See [1] for a discussion of the first three of these workshops and [2] for an account of an individual postgraduate's experiences of teaching.

As the workshops progressed a unifying pattern began to emerge of the training needs for postgraduates and this is developed further within this article.

The initial programme for the workshops consisted of four sessions:

- Planning and Delivering Small Group Teaching;
- Facilitating Problem Solving Classes;
- Encouraging Participation: Motivating and Sustaining Student Interest;
- Assessing Student Work and Providing Feedback.

An interactive Question and Answer session concluded each workshop and provided participants with the opportunity to seek advice and share advice, and discuss their individual concerns. The workshops were all facilitated by experienced teachers of mathematics within HE, and were offered at three locations within England. As a result, a set of materials have emerged from the sessions providing a substantial and developing resource for subsequent participants [3]. There was a good spread of experience amongst the participants who attended these events which ensured a lively and productive exchange of views and ideas.

Almost immediately, other departments of mathematics were requesting similar workshops for their own postgraduates, and a further two events were scheduled for individual institutions in 2006 with others planned for subsequent years. It is intended that the structure and format of this workshop series will continue to develop and evolve, and feedback from participants and other evaluation mechanisms in 2005/2006 suggested a few changes to the structure of the workshops which now consist of a greater number of shorter, more diverse sessions:

- The First Lesson;
- Planning and Delivering Small Group Teaching;
- Facilitating Problem Solving Classes;
- Presenting & Communicating Mathematics;
- Assessing Student Work and Providing Feedback;
- Interactive Session: Sharing Advice.

During the first phase of the workshops, a total of 88 postgraduates attended. Feedback from participants has been extremely positive: narrative comments indicate that many will re-think how they plan, organise, and/or present their teaching sessions. In our view, the message is clear: no matter how much lecturers and colleagues think about courses they are delivering, for as long as a significant amount of teaching is left in the hands of postgraduate students, they must be appropriately supported and trained, which in our experience they welcome enormously, and this must include a discipline specific component. Otherwise this will remain the 'weakest link' in the learning and teaching provision.

**Background**

A survey of postgraduates' training needs [1] confirmed that most are involved in running seminars or tutorials or problem classes of some kind in Mathematics or Statistics, 40% are involved in marking exams and about half marked coursework. Postgraduates perform such a wide range of duties directly interacting with undergraduate students, that it was not initially clear how best to support them. However, during the course of the workshops a pattern emerged, with the help of the postgraduates themselves, which seems to provide a natural approach to such training. This is described here, but of course is likely to evolve in response to further feedback. In any event, our main objective was to ensure that all participants had the opportunity to receive targeted advice and support.

Normally postgraduates teach in a small group environment, or are directly involved with either demonstrating how to solve problems, or assisting students in their attempts to solve problems. In relation to assessment, they are normally marking formative student assessment and providing feedback. Therefore, while they are not usually responsible for an entire undergraduate course, postgraduates are actually in the 'front line' when it comes to supporting student learning. We can perhaps summarise the basic skills needed by the postgraduates as follows. Postgraduates have to:

- **ENTHUSE** the students about mathematics;
- **ENGAGE** the students in productive mathematical work;
- **EXPLAIN** mathematics to students with varied backgrounds;
- **EVALUATE** student work and mark in a fair and consistent manner.

While the workshops were not initially structured in this way, it naturally evolved as a way to focus on specific skills the postgraduates needed in the context of Mathematics and Statistics. These skills are central to teaching mathematics by any means, and are particularly difficult to master especially by those new to teaching.

**Enthusing Students About Mathematics**

The postgraduates were encouraged to at least give the appearance of enthusiasm, even if they found a topic uninspiring. In fact, with sufficient imagination there is no branch of mathematics that can't be made interesting. Self awareness and self discipline are needed in order to adapt when you feel you are becoming jaded or boring. A teacher might raise enthusiasm by asking questions such as:

- History of the topic, where did it come from and why?
- Where does it lead to, what areas of mathematics/statistics are built on it?
- What sort of applications does it have?
- Can I derive any of the results in it by different methods?
- Can it be generalised?
- How is it related to my own particular area of interest?
- Why do the students need this, and why should they find it interesting?
- What concepts are at the core of the topic, and where else do these occur? How did the original developers of the ideas find their way through them?

Students are more likely to become enthusiastic about a topic if they appreciate the few core points upon which it is based. Emphasise these to the students so that they have anchors for their ideas, and then motivate and explain why these points are so important, highlighting any interesting features along the way. Provide examples and asides that may be of direct relevance/interest to them (which does not necessarily mean in their own subject area).

The students' curiosity can be aroused by posing 'interesting questions' and then by being persistent in obtaining answers. An occasional short amusing story related to the topic in hand can sometimes spark genuine interest. Sometimes, you can ask the students for their help, for example on something they may have covered in another topic. When talking to the students, try to justify sensibly, as well as logically. Discuss their notes with them. Choose problems that are at 'just the right level'; too easy can be uninspiring, too hard demoralising. If all else fails in eliciting interest, then regular reference to the examination usually does the trick!

As a group exercise the postgraduates were asked to think of a tedious piece of mathematics and then treat it in an interesting way. You will be glad to hear of one workshop at which they couldn't think of anything boring in Mathematics as they loved it all! One group suggested the topic of convex sets, after all what could be more boring than the definition of a convex set? But, why do we need convex sets and what makes them so important and actually very interesting? Well, in a convex set you can always move between any two points by the simplest path imaginable, a straight line. That sounds quite interesting, surely? Vertices representing optimal points can therefore be located by scanning a convex set with straight lines, again, surely interesting? But how many sets do we know are convex? Aren't they just a rather unrepresentative case and therefore not that interesting really? But can't we always break up most sets into separate pieces that are convex, treat those separately and then put them back together again? In other words, what we can do with a convex set you can usually stretch to any set. The point is that while the dry definition of a convex set may be pretty uninspiring by itself, the teacher can make it much more interesting by providing a few minutes of additional background information.

**Engaging Students in Productive Mathematical Work**

Postgraduates are often employed in a tutorial or problem solving situation and one of their main tasks is to actually get the students involved, to get them working productively and keep them at it. The importance of preparation in incorporating activity into a session was emphasised. The purpose of the session must be made clear to the student, with succinct instructions for any activity. Learn as much as possible about the students and remember that they will not necessarily be as motivated or able as you.

To establish the right classroom atmosphere start the session off in a business-like way. Ensure that the student has all necessary resources for the session. Indicate some sort of schedule, and set clear ground rules about orderly conduct of the class. Once started, keep things going. Be everywhere and make sure everyone is active. Help them with entry methods to problems. If they are struggling, tell them to try anything at all, and that sensible guessing is fine. Keep to schedule and ensure even coverage of material. Encourage students to use their notes, books, and other resources as appropriate and to create their own learning materials. When working through problems on the board, you are simply the scribe, most of the working should be obtained from the students themselves, and not just the more able ones. As an exercise in engaging students, one workshop incorporated a role-playing session with the postgraduates acting out different stereotypes within a small group environment. The objective of this exercise was to get all students engaged in the activity, even though some had particularly recalcitrant roles! This worked very well and gave the postgraduates a number of tips and ideas that could be used within their own teaching.

If a student is struggling and not making progress, don't rush in to rescue them completely, but provide them a little help along the way. For example in solving a differential equation by integrating factor method many students have difficulty even starting the problem. Don't jump straight in and find the integrating factor for them. Instead, give them a few suggestive products to differentiate, get them to think about the purpose of the integrating factor. For the very weak student, tell them to find an example in their notes and repeat it line for line with the new equation. The overall purpose is to get the student working and thinking, not necessarily to show them how to solve the equation.

Related to the job of keeping the students engaged is the difficult task of maintaining a disciplined and productive working environment. This was raised as an important issue for postgraduates and is sometimes a problem even for experienced staff. As they have recently graduated from students themselves, postgraduates may lack confidence in their role and status. On the other hand they have the advantage that they are 'closer' to the students and may appreciate their difficulties more readily. To assist in keeping things under control, the postgraduates were encouraged to be clear about their duties, responsibilities and status. Set ground rules early on and stick to them. Keep order. Never be rude, sarcastic or derogatory. Allow leave only for essential purposes. Keep on task, and be aware of any diversity issues, for example non-native speakers.

**Explaining Mathematics to Students with Varied Backgrounds**

Explaining is one of the key arts of teaching [4]. You don't explain by telling, but by listening, learning, and dialogue with the student(s). You first have to find out what the students know so you can 'get on their wavelength', and be sure you understand what 'know' means for your students. Ask the typical first year undergraduate if they 'know' the product rule in differentiation and they will invariably say 'yes'. But whether they will readily recognise its reversal in the integrating factor method mentioned earlier is far less certain. Having established a common language and starting point lead the student through gradually, dangling the next step just close enough to encourage them to move forward, you may have to break off and tell them to go and think about it for a while. Don't be afraid to let them follow a route that may go nowhere; teach them how to backtrack and start again. And when they finally achieve the correct solution, be pleased with them and hurry them on to the next topic. Never use any sort of negative, derogatory or demeaning response to a student's question. Be polite and helpful, but remember, you don't necessarily have to give the student everything they ask for.

The postgraduates were urged to prepare well for their sessions, so that they themselves can solve all the problems in a way in which the undergraduate is expected to solve them. With their superior knowledge they may know a number of different methods for tackling a given problem, but how is the student supposed to solve it? For example an expert may do a Partial Fractions decomposition very quickly by the cover up rule, but have the students been introduced to this? On the other hand, if the student is mastering the subject, then they might be exposed to the other methods to stretch them a little. Postgraduates were therefore advised to develop a 'global' overview of a topic, with a range of different approaches, so they can adapt to different teaching situations as required.

As a group exercise at the workshops the postgraduates were asked to choose a particularly difficult piece of mathematics or statistics, at any level, and prepare a short presentation (5-10 minutes) explaining this topic to a typical first year student in terms they are likely to appreciate and understand. At one workshop a postgraduate proposed a presentation on homology groups, and we began to get worried that the exercise might not work as intended. However, the postgraduate student made an excellent job of it, demonstrating perfectly how even the most difficult ideas can be explained simply by: paraphrasing technical terminology and notation; the careful use of visual imagery; appropriate analogues; and, providing a range of viewpoints, both converging and diverging. At a more mundane, but no less challenging level, another workshop looked at explaining completing the square to Engineering undergraduates. In this instance, the explanation is usually made difficult because students are not given a clear view of the key ideas involved (expansion of $(a + b)^2$ and $A - A = 0$) and lack sufficient skills and fluency in the use of these. Therefore, another key pre-requisite of good explanation is ensuring that the basic key components are fully understood by the student beforehand.

**Evaluating Student Work and Marking Fairly**

The postgraduate participants at the workshops also had the opportunity to mark authentic student work. They marked three students' attempts at expanding $(2 + 3x)^6$ by the binomial expansion theorem and were asked to discuss what a typical marking scheme might look like for this problem. The table below shows the spread of marks awarded at one workshop (out of 6) for the three examples of typical undergraduate attempts. In the actual exam all students made different types of errors but obtained the same overall mark of 4/6.

| Student/Mark | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| A | 0 | 0 | 2 | 12 | 8 | 0 | 0 |
| B | 0 | 0 | 1 | 3 | 5 | 7 | 3 |
| C | 0 | 1 | 5 | 2 | 6 | 1 | 0 |

The important point emphasised here was that it is necessary to be very clear about the skills being assessed and the learning outcomes being examined. For example, one undergraduate attempt only made the common mistake of omitting the '3' in the expansion, and so all but one of their coefficients were incorrect. However, this cannot be penalised too strongly because they had remembered the binomial theorem formula, evaluated the binomial coefficients correctly, obtained the correct powers, and yet appeared to get 'everything' wrong because of one slip at the beginning. Some postgraduates thought lack of explanation should be penalised heavily, but there was no hint in the question that this was called for. Discussing such issues the postgraduates came to see the importance of a good marking scheme. If nothing else this exercise taught them that there was plenty of room for debate about marking even the simplest of questions, and indeed in their feedback a number of them said they would mark more thoughtfully in future.

**Some Lessons Learned**

Formal question and answer sessions were introduced in the second and third workshops, with postgraduates submitting beforehand their most pressing questions so that all participants left the session feeling that their individual concerns had been addressed. This provided a lot of material for discussion. The questions and suggested responses (on issues of small group teaching and running problem classes) for the second workshop were collated, written up and distributed to all delegates and can be found on the Network's web-site [3]. They are most likely questions that every postgraduate teaching assistant will have at some time or other.

In their feedback the delegates gave clear directions for the sort of training they value:

- Lots of practical and hands on exercises;
- Opportunity for sharing ideas and engaging in discussion with others;
- "Nuts and Bolts" no-nonsense explanation and advice;
- Obtaining answers to their individual questions;
- Unified overview of teaching and learning issues;
- Emphasis on the importance of teaching;
- Enthusiastic and dynamic delivery.

We believe we have made a good start in supporting this range of provision and there is little doubt that there is a substantial need to be met as more and more institutions are requesting these workshops for their postgraduate students. Also, there were some suggestions for other sessions the postgraduate teaching assistant would like to see, for example sessions devoted to a wider range of topics such as the special considerations involved when using IT to teach mathematics or sessions designed around the needs of non-native speakers.

**Postscript**

The workshops described in this article were funded and delivered by the Mathematics, Statistics and Operational Research Network, a Subject Centre of the UK Higher Education Academy. As such they represent a small, but important part of an overall aim of promoting, disseminating and developing good practice in learning and teaching across UK Higher Education. Further details of the work of the Network may be found on our website [5]. The Network is keen to hear of related initiatives, whether in the UK or overseas, and publishes a wide variety of contributions in a regular Newsletter '*MSOR Connections*' [6].

**References**

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