Institution: Loughborough University

Unit of assessment: C23 Education

Section 1. Unit context and structure, research and impact strategy

1.1 Research Structure

The Mathematics Education Centre (MEC) at Loughborough University is a department within the School of Science. We have undergone transformational growth in the last decade: between RAE2008 and REF2014 we grew from a teaching-focused unit with some specialist research into a high-performing but small interdisciplinary centre bringing together researchers with backgrounds in mathematics, education and psychology. In REF2014, 85% of our research was deemed internationally excellent or world leading. Since then, we have maintained our focus on mathematics education but have increased our research quality, substantially increased our impact, and more than doubled in size from 7.7fte to 18.4fte.

This step change has been possible through internal investment, a broad profile of externally funded activity, and a 2019 £6.6m 'Expanding Excellence in England' (E3) award from Research England to set up a new E3 Centre for Mathematical Cognition (E3-CMC). This exciting expansion has allowed us to further develop our vibrant research environment by investing in permanent academic posts, research and enterprise fellowships, postdoctoral positions, PhD studentships and administrative support. Significantly, the MEC is now formally recognised as a Centre of Excellence in CALIBRE, the research component of the University strategy *Building Excellence*, making us a priority for internal investment. The excellence of our research environment is also recognised externally: in the citation to the 2017 Times Higher Education Outstanding Research Supervisor of the Year Award, the judges described the MEC as being "an internationally outstanding research environment with state-of-the-art equipment".

Our research is organised around three overlapping themes: *mathematical cognition*, *design and evaluation*, and *higher education pedagogy*. The *mathematical cognition* theme investigates students' understanding of numerical concepts, and their logical and mathematical reasoning. The *design and evaluation* theme designs pedagogical interventions based on sound understandings of mathematical learning processes, and rigorously evaluates them. The MEC contains the UK's largest group of researchers working on undergraduate mathematics education, and our *higher education pedagogy* theme provides a focus for research on university-level mathematical teaching and learning. Colleagues collaborate across all three themes via both formal and informal mechanisms.

The MEC is an overtly **interdisciplinary** research unit. Staff in our return are trained in education, mathematics, developmental psychology, cognitive psychology, neuroscience, health, and philosophy, and during the assessment period we have published in specialist journals in each of these areas. Our collaborations range across the sciences, social sciences and humanities. For example, during the assessment period we developed a collaboration with medics (UCL), health researchers (Leicester), and psychologists (Nottingham) to investigate the impact of premature birth on school mathematics achievement. The project established, for the first time, that the mathematics difficulties faced by very preterm children have a different aetiology to dyscalculia. Work with philosophers at McGill and the Florida Institute of Technology pioneered the use of social science methods to study philosophical issues, such as the nature and role of mathematical aesthetics. This led to the first edited volume on the 'experimental philosophy' of mathematics. We celebrate the diversity of our expertise and experience – it is one of the MEC's core strengths.

1.2 Progress Against 2014 Research Strategy

The MEC's research strategy, as outlined in REF2014, committed us to conducting research in mathematics education that achieves the highest levels of international excellence and recognition. To this end, we set five specific objectives. The strategic use of the additional QR

funding resulting from REF2014 has enabled significant progress against each.

Objective 1: Maintain our position as an internationally leading research group focused on mathematics education at HE level, and expand our growing international reputation for research in mathematical and numerical cognition.
Our international reputation for undergraduate mathematics education was further enhanced by Inglis's receipt of the 2014 Selden Prize for Research in Undergraduate Mathematics Education from the Mathematical Association of America, for "a significant record of published research in undergraduate mathematics education". A particular highlight of our undergraduate-focused work was Alcock and Inglis's programme of research that developed and tested materials which facilitate undergraduate students' comprehension of mathematical proofs, a central component of higher-level mathematics education.

We are now recognised as an international leader in mathematical cognition research, as demonstrated by Research England's decision to establish the E3-CMC. We have also contributed to the field more widely: in 2018, Gilmore and Inglis (with Göbel, York) published the first masters-level textbook on mathematical cognition to positive reviews ("Everyone interested in mathematical cognition will want to have this book", Robert Siegler, Carnegie Mellon).

Objective 2: Retain early career staff who have joined the Centre in recent years and support their transition to become international research leaders.
Since 2014 our early career staff have prospered. Gilmore commenced her Royal Society Dorothy Hodgkin Research Fellowship in 2014, was promoted to Reader (2015) and Professor (2020). Jones completed his Royal Society Educational Research Fellowship in 2014 and was promoted to Senior Lecturer (2017) and Reader (2020). Inglis completed his Royal Society Educational Research Fellowship in 2015 and was promoted to Reader (2015) and Professor (2018). In 2020, Gilmore was awarded the Experimental Psychology Society (EPS) Prize, which recognises "distinguished, independent and original contributions to experimental psychology". This high-profile recognition, and the quality of the underlying research, led to the establishment of the £6.6m E3-CMC, which Gilmore and Inglis direct.

Objective 3: Maintain a dynamic, well-supported research environment by continuing to invest in research infrastructure.
Our physical research environment has been transformed during the assessment period. A university-funded £4.25m refurbishment of our building created purpose-built research laboratories and social space to facilitate interaction between staff and research students. A further £250k was subsequently invested in refurbishment of additional office and research space to house the new E3-CMC.

Objective 4: Expand the range of sources from which we derive research income.
Since 2014, the MEC has attracted funding from a range of sources including Action Medical Research, British Academy, ESRC, Leverhulme Trust, Nuffield Foundation, Research England and the Royal Society. Our research expenditure during the assessment period represents a substantial increase on REF2014 (£1.4m v £862k). Our success in REF2014 enabled us to join an ESRC DTP, the Midlands Graduate School, which has significantly increased the size and quality of our doctoral cohorts. A highlight has been a series of projects, funded by the Royal Society, AQA and Nuffield Foundation, which explored how comparative judgement techniques can assess conceptual understanding in mathematics. This work led to our impact case study "Transforming educational assessment with comparative judgement".

Objective 5: Support the mathematics education community by hosting an increasing number of high-quality workshops and conferences which will attract international researchers.
Our research workshop series has for many years attracted researchers from across the Midlands. We have used our increased post-REF2014 QR funding to host an annual international symposium at Loughborough. In 2014, we were awarded funding by the Royal Society to bring together researchers from eleven leading international research groups to

collaboratively identify priority research challenges in mathematical cognition. The resulting 2016 *Journal of Numerical Cognition* paper, which recommended greater interdisciplinary collaboration between education and psychology researchers, was widely discussed in the community.

1.3 Progress Against 2014 Impact Strategy

Knowledge exchange is at the heart of the University strategy *Building Excellence*. Enterprise, defined as the creation of "social, cultural and economic impact through knowledge exchange", is core to the University's mission alongside research and teaching. The MEC has proactively engaged with this agenda. Promotion and reward criteria recognise staff who excel in enterprise: staff can be awarded personal chairs based primarily on impact activity and the School of Science's flexible workload model allows time to be allocated to specific impact projects. Progress against our four REF2014 objectives is outlined below.

Objective 1: Increase levels of external funding for impact-generating activities.
Since 2014 we have completed impact-related externally funded projects worth £1.9m, up from £733k in the previous REF period. Particular highlights include support from HEFCE for the Sigma Network's mathematics and statistics support activities (which led to our impact case study 'Addressing the quantitative skills deficit in higher education'), our participation in the £433k HEFCE-funded Transforming Transitions project, and the Erasmus+ PLATINUM consortium which developed inquiry-based pedagogy for undergraduate mathematics.

Objective 2: Maintain and expand the scope of our networks of practitioners.
Following the end of HEFCE-funding in 2016, the Sigma Network has transformed from being an externally funded research and development project into a professional association for mathematics support practitioners. We have developed similar networks of other educational professionals. For example, building on our established PGCE partnership of 59 schools, in 2019 we established the Loughborough University Mathematics Education Network (LUMEN), a group of 111 mathematics teachers who engage in professional development activities focused on embedding insights from research in the classroom.

Objective 3: Be involved in the organisation of major practitioner conferences.
The Sigma Network organises an annual conference on mathematics and statistics support. Since 2014, an average of over 100 delegates (from over 50 institutions) have attended each year. We have also contributed to the Institute of Mathematics and its Applications (IMA) Teaching and Learning Workshop series. In 2018, the IMA-funded Effective Learning event brought together 150 higher education students and lecturers to hear MEC researchers describe educational research findings, and their implications for the teaching and learning of undergraduate mathematics.

Objective 4: Develop our relationships with key external bodies.
Staff have engaged with educational stakeholders, with much success. For example, Jones developed a collaboration with exam boards such as AQA, focused on comparative judgement techniques in assessment. This led to the foundation of No More Marking Ltd, as described in our case study 'Transforming Educational Assessment with Comparative Judgement'. We have also engaged with policymakers and educational charities: Jones was the only mathematics education researcher on the Royal Society's Vision for Science and Mathematics Education 5-19 Committee.

Our overall strategy for generating impact has involved two main routes. First, we cultivated networks of practitioners in both schools and universities who wanted to engage with our research by informing our priorities, participating in research activities, and developing their practice using our research insights. Second, we developed partnerships with external educational bodies who wanted their work to be more research-informed. Our two **impact case studies** in this return exemplify each of these routes. The HEFCE-funded Sigma Network has supported the establishment of Mathematics Support Centres at universities across the UK, and

has formed a community to share best practice and reusable learning resources. The establishment of No More Marking Ltd was a direct result of Jones's collaboration with AQA, developed as part of his Royal Society Fellowship on assessing mathematics.

1.4 Research and Impact Strategy from 2020

1.4.1 Research Strategy

Research themes. Our research is structured around three research themes: *design and evaluation* (D&E), *higher education pedagogy* (HEP) and *mathematical cognition* (MC). We encourage interaction between themes so that fundamental research on learning conducted in the MC theme is informed by the priorities of educational designers, and that novel educational designs produced in the D&E and HEP themes are informed by rigorous research on learning. To facilitate collaborations across themes, we will encourage the formation of ad-hoc research clusters to run informal reading groups and develop specific funding applications. Clusters are priorities for internal pump-prime research funding. To further promote cross-theme discussion, our MEC-wide workshop series integrates contributions from across our themes.

Objectives. In line with the University's strategy, *Building Excellence*, our overall aim for the next assessment period is to conduct research in mathematics education that achieves the highest levels of international excellence and recognition. Specific strategic objectives are to:

1. Establish the E3 Centre for Mathematical Cognition as the world's leading centre for educationally relevant mathematical cognition research. We will ensure that our fundamental research on mathematics learning informs, and is informed by, both high-quality educational design (D&E), and research on higher education pedagogy (HEP).
2. Retain staff who have joined the Centre during the recent E3 expansion and support their ambitions to become internationally leading researchers.
3. Expand research capacity in mathematics education by employing and training an increased number of postdoctoral researchers, funded via competitive research grants, and by increasing our research student numbers.
4. Contribute to the development of mathematics education as a discipline by organising internationally regarded symposia, and supporting staff to undertake leadership roles in journals and learned societies.

In addition to these strategic objectives, we have set specific priorities for each research theme:

- The MC theme will expand its research on numerical development by addressing the question of how children assign meaning to numerical symbols. Specific aims are to (i) disentangle the role that cardinal and ordinal information play in numerical symbol learning, (ii) understand the domain-general and domain-specific cognitive predictors of early numerical understanding, and (iii) test whether these predictors are causal by evaluating experimental interventions.
- The D&E theme – created as part of the E3-CMC expansion – will design, develop and evaluate pedagogical interventions informed by a rigorous understanding of student learning; it will also contribute to debates across education about the ways in which evidence informs practice. Specific aims are to (i) develop and evaluate game-based learning resources that assist with children's numerical development, and (ii) conduct research on how randomised controlled trials can be designed, and their results communicated to teachers, more effectively.
- The HEP theme will expand its highly regarded work on the study of HE mathematics and statistics pedagogy, the design of learning resources and assessments, and the development of mathematical expertise. Specific aims are to (i) develop novel assessment methods in undergraduate mathematics, including the assessment of conceptual understanding, and (ii) study undergraduates' and experts' mathematical reasoning.

All of this work will be underpinned by our interdisciplinary culture and commitment to open research and research integrity.

1.4.2 Impact Strategy

Our aim is to encourage all staff to engage in impact-generating activities. Central to our strategy from 2020 is the appointment of 2.2fte Enterprise Fellows (EFs). The remit of the EFs is to work across the MEC to ensure that our research is informed by the priorities of practitioners and that research which has the potential to create wider impact achieves this. Two postholders (Francome, Shore) are experienced teachers with considerable experience in translating research into practice, the third (Perini) is an expert in textbook design. Shore combines his 0.4fte role at Loughborough with leading the East Midlands South Maths Hub, which covers over 570 schools, ensuring that our work remains tightly connected to practice.

The EFs will work with the MEC's Enterprise Coordinator (Jones) to support and increase the visibility of our existing high-quality impact work, and develop new activity. From research developed since 2014, priorities for future impact include:

- Game-based learning. Jay and Moeller have expertise in translating insights from research on psychology and neuroscience into impact on children's mathematics learning through the design of digital games. For example, Jay led a two-year project funded by the Leverhulme Trust to design a mobile game that supports children's arithmetic fluency. The game is currently being prepared for wide distribution and for further research on its effectiveness at scale.
- Work that harnesses research insights to improve learning in undergraduate mathematics education. Alcock's OUP-published books (*How to Think about Analysis*, *How to Think about Abstract Algebra,* and *How to Study for a Mathematics Degree*) have sold over 31,000 copies since 2014. We aim to explore additional routes (e.g. online resources, MOOCs) through which these insights can reach wider audiences.

We have set three specific strategic objectives related to impact for the post-2020 period:

1. Develop and test interventions, including game-based learning resources, designed to improve children's early mathematical skills (D&E, MC).
2. Support activities that enable our world-leading research on undergraduate mathematics education to positively impact on the quality of teaching and learning in higher education (D&E, HEP).
3. Design and share resources that increase the impact of our research on assessment, particularly by developing comparative judgement tools (D&E, HEP).

While working towards these objectives we will continue to develop collaborations with research users and beneficiaries, building on our existing network of partners.

1.5 Open Research

The MEC is a pioneer of Open Research. Gilmore chairs the University's Open Research Working Group, which is responsible for implementing Loughborough's new and comprehensive Open Research position statement.

Our leadership in this area builds on an impressive track-record. In the citation for Inglis's 2014 Selden Prize, the Mathematical Association of America noted that he had been "publicly recognized by the editorial team of the *Journal for Research in Mathematics Education* as a model for how the field should share data and contest data interpretations". Wege (an MEC doctoral student) is Loughborough's UK Reproducibility Network (UKRN) lead, and together with Strauss (another MEC doctoral student) organises a journal club, known as ReproducibiliTea, to share Open Research best practices.

In 2016, Loughborough became one of the first UK universities to adopt a responsible metrics policy, based on the Leiden Manifesto. This commits us to using publication indicators only to support rather than supplant peer review, and to acknowledge and mitigate their inevitable limitations. The MEC fully supports the responsible use of metrics. All staff in this return are individual signatories to the San Francisco Declaration on Research Assessment, principles from which informed our recruitment strategy.

In 2017, the MC theme adopted an Open Research policy that goes well beyond the University's normal expectation. Built on the Manifesto for Reproducible Science, this policy commits researchers to (i) preregister all analyses involving null hypothesis significance tests and (ii) archive anonymised data, analysis scripts, and research materials prior to manuscript submission. We make full use of the University's Research Repository (since 2019), which unified predecessor repositories for text-based outputs (since 2005) and data (since 2015). Papers are deposited immediately upon acceptance, exceeding the REF2021 requirement.

1.6 Research Integrity
Loughborough's Ethical Policy Framework steers the work of the Ethics Committee, whose membership includes lay members and academic representatives. The Ethics Committee considers all ethical matters arising in the conduct of the University's business and is guided by a Code of Practice underpinned by the five principles of UUK's Concordat to Support Research Integrity.

The Ethics Committee oversees the work of the Ethics Approvals (Human Participants) Sub-Committee, on which Inglis and Xenidou-Dervou sat during the assessment period. The sub-committee ensures that our research is conducted to ethical standards consistent with the British Educational Research Association's Ethical Guidelines for Educational Research. A Research Misconduct and Whistle-Blowing Policy allows staff to report issues of research misconduct without fear of recrimination, supporting a culture of research integrity. This structure ensures that the MEC's research is ethically responsible.

Section 2. People

We aim to provide a vibrant and supportive environment that encourages and recognises success. We benchmark our progress using regular University-wide staff surveys. These reveal a positive work climate. In 2016, 100% of MEC staff stated that they 'generally enjoy their work', and 93% said they 'get good support from their colleagues'. Both figures are well above the sector averages (91%, 89% respectively).

2.1 Staffing and Recruitment Strategy
Our staffing strategy involves the recruitment of academics with excellent research profiles in our strategic research themes, coupled with career development support at all levels via mentoring and fellowship opportunities.

We have expanded significantly during the REF assessment period. In line with recommendations from the *Concordat to Support the Career Development of Researchers*, we search internationally to recruit the most promising academics in the areas defined by our research and impact strategies, and our teaching needs. Given the University strategy *Building Excellence* and our commitment to the San Francisco Declaration on Research Assessment, we focus on applicants' research excellence rather than the quantity or venue of their publications.

Our recruitment strategy enabled us to successfully manage both **succession planning** and the substantial recruitment activity associated with the new E3-CMC. Between 2014 and 2018, Tanswell and Xenidou-Dervou joined as lecturers, Hewitt and Iannone as senior lecturers, and Foster as reader. Our bespoke E3-CMC recruitment campaign launched in 2019 and aimed to recruit new academic colleagues across all levels of seniority. In early 2020 we successfully appointed two professors (Jay, Moeller), two senior lecturers (Lortie-Forgues, Morsanyi), four lecturers (Bahnmüller, Chen, Cipora, Sella), two research fellows (Pickering, Trezise), three enterprise fellows (Francome, Perini, Shore), and four postdoctoral research associates (Ferreira, Rittberg, Şimşek, Trickett). Over 40% of these appointments joined us from international institutions – including VU Brussel, Chicago, Tübingen, and NIE Singapore – confirming the international reach of our recruitment activities.

2.2 Staff Development Strategy

Staff development is central to achieving the objectives set out in our research strategy. While we follow the seven principles of the *Concordat to Support the Career Development of Researchers*, the exact mechanisms we adopt vary by career stage.

Technical Staff. Loughborough was a founding signatory of the Technician's Commitment, which acknowledges and aims to remedy the under-appreciated role of technicians working in higher education research with recognition, sustainability, visibility and career development through a formal action plan. This has enabled our Technical Tutor (Patel) to access professional development opportunities, for example NEBOSH health and safety courses.

Postdoctoral Researchers. Each postdoc is assigned a mentor whose role is to support their wider career development. Postdocs are encouraged to engage in University-wide development opportunities including the 'Recognition of Teaching for Researchers' scheme, which results in Associate Fellowship of the Higher Education Academy (HEA). The Research Staff Association provides a link to the wider university community, and we ensure that all postdocs are associated with at least one MEC research theme, giving a structure for sharing ideas and developing joint projects. Our postdocs have enjoyed notable success since 2014. For example, Bisson was appointed to a lectureship at De Montfort (and subsequently promoted to senior lecturer) and both Rittberg and Şimşek took up individual fellowships (funded by the European Commission and ESRC respectively) in October 2020.

New Lecturers' Programme (NLP, formerly probation). During their first three years, new lecturers have protected teaching loads (1/3, 1/2 and 2/3 of the departmental norm) and light administrative duties. They engage in individual mentoring programmes structured according to their background and experience, and discuss research activity and future plans with an academic advisor. At least four formal meetings take place between adviser and advisee per year, but many more informal meetings are the norm. New Lecturers are allocated a University-funded PhD studentship within their first two years, and these students are co-supervised by experienced colleagues. They also undertake the University-wide Academic Practice Taught Course, which results in Fellowship of the HEA and includes units introducing the University's wider research culture. This structure allows New Lecturers to develop their expertise across all aspects of their role in a supportive environment. Rapid promotion has been the norm in the MEC. For instance, Xenidou-Dervou joined as a lecturer in December 2015, completed NLP following a period of maternity leave in 2019, and was promoted to senior lecturer in January 2020.

Mid-Career and Senior Staff. Mid-career and senior staff are encouraged and supported to take leadership roles across the institution. During the assessment period, Robinson served as Director of the University's Centre for Academic Practice, and Inglis served as Loughborough UCU Branch Chair. Both were supported in these important leadership roles by significant allocations on the School's workload model, ensuring they could maintain substantial levels of research activity. Further support is provided for mid-career and senior staff via a promotion mentoring scheme where senior staff mentor colleagues through the promotion process.
We strongly encourage all staff to apply for fellowships appropriate to their career stage. During the assessment period, MEC staff have held three Royal Society Research Fellowships, a British Academy Postdoctoral Fellowship, and an ESRC Future Research Leaders Fellowship. In addition, Loughborough offers University Fellowships permitting colleagues to suspend their teaching and administration duties for up to a year to concentrate on a specified research or impact project, supported by £5000. Fellowships may also be used to facilitate exchanges with partner organisations. Proposals are rigorously and supportively peer reviewed within the School and at the University level. During the assessment period, six MEC staff have held University Fellowships for a total of 54 months. Colleagues returning from parental leave are particularly encouraged to apply to this scheme, and have preferential access (Xenidou-Dervou's Fellowship was a result of this policy).

Appraisal, Promotion, and Reward. Every post-probationary member of staff, including professional services colleagues, participates in the annual Performance and Development Review (PDR) process, which was transformed in 2016/7. A goal of the new process was to ensure 100% of research staff participated. This has been achieved.

In the research and enterprise component of PDR, staff reflect on their achievements over the past year and set plans for the next. PDR can result in targeted support (additional resources for training, or workload hours for specific impact projects), entry into the University's reward process, or encouragement to apply for promotion. Rewards range from additional salary increments to funding teams to celebrate significant outcomes. Reward outcomes are carefully evaluated against protected characteristics and action plans put in place if necessary. The reward process embeds a supportive culture in the MEC where celebrating colleagues' achievements is the norm. The promotion process has also been transformed during the assessment period. It is now possible to be promoted (up to and including a personal chair) based on any profile of research, teaching and enterprise activity. In research, the quality of outputs is emphasised over their quantity or publication venue.

2.3 Research Students

The MEC's recent growth is reflected in its research student population: nearly three times as many students have completed PhDs in this assessment period compared to REF2014 (all are traditional PhDs; we do not offer professional doctorates).

2.3.1 Research Student Funding and Recruitment.

Our status as a Centre of Excellence under the University's CALIBRE framework means we have been a priority for internal studentship funding: during the assessment period 18 students have been funded via this mechanism. We are members of the ESRC Midlands Graduate School (MGS) DTP, founded in 2017, and offer an MSc in Social Science Research Methods (Education). We have been awarded 8 DTP competitive studentships which, despite our small size, represents 31% of all the MGS education pathway studentships. During the assessment period, we have also received funding for studentships from Research England, the Royal Society, and the Indonesian, Maltese, Nigerian and Turkish governments.

Our research student recruitment reflects our commitment to equality and diversity. Studentships are advertised via jobs.ac.uk and FindAPhd.com. We require a good first degree in a discipline relevant to the proposed research, and that candidates demonstrate they can undertake sustained independent research. Admission decisions are taken by two colleagues following an interview. The Research Coordinator allocates supervisors, taking account of research expertise, workload and supervisory experience.

2.3.2 Research Student Monitoring and Support.

The quality of the research environment we provide for research students was recognised in 2017 by the award of the Times Higher Education Outstanding Research Supervisor of the Year award to Inglis. In their citation, the judges noted that we offer our students "a permeable research culture, chances to win funding, workshops, research group meetings and observational laboratories and access to international networks and careers advice, as well as providing opportunities to publish". They concluded that the MEC is "professionalising the whole doctoral education experience".

Direct academic support for research students is provided by supervisors, who meet their students at least monthly and usually much more often; minutes are recorded online. However, support extends far beyond this. Students participate in the MEC's fortnightly research workshops, and hold a graduate student seminar the following day to discuss the experience and to pursue self-directed development activities. Each student participates in meetings of the research theme(s) most relevant to their work, and is encouraged to contact any staff member for additional specialist guidance. Publishing is encouraged, and students are enthusiastic participants in our internal peer review scheme. Generous funding is provided to support

research and conference attendance; for University-funded students, this amounts to £500-£1000 per year for research expenses and up to £2000 across the PhD for travel.

More broadly, the University offers a Statistics Advisory Service and an English Language Support Unit. Students with disabilities are supported by the University's Counselling and Disability Service. The Doctoral College is responsible for the delivery of **transferable skills training** to meet the requirements of the Researcher Development Framework. A wide portfolio of training courses for doctoral students are offered, as well as poster competitions and interdisciplinary conferences, and funding to support travel for research and conferences.

To monitor supervision and ensure that progress is consistent, we require a major academic progress review against published criteria at the end of each year of registration. Students are required to produce a significant piece of written work and to undertake an interview with an independent assessor before progressing to the next year of registration. This provides external input and early experience in preparation for the eventual viva. Our progression system has led to a high-level of timely completion: during the assessment period the average start-to-submission duration for full time students was 42 months.

Within the School, quality assurance of research degree programmes is provided by the Associate Dean (Research) who is a member of the University's Research Committee. At the institutional level, quality assurance is provided by the Associate Pro Vice-Chancellor (Doctoral College), who is responsible for ensuring consistent and equitable treatment. The Doctoral College leads a cycle of regular research degree programme reviews, the outcomes of which are reported to the University's Research Committee.

2.4 Equality and Diversity

We are committed to supporting all staff and students to reach their potential, regardless of background or circumstance. The four-strong MEC Senior Management Group is 75% female, and 50% of its members work part-time to accommodate caring responsibilities. Following a 2015 submission co-led by Gilmore, the MEC and Department of Mathematical Sciences jointly received an Athena Swan silver award recognising the steps that we take to ensure gender equity. The MEC enthusiastically participates in the School of Science's wider equality and diversity initiatives. This work is overseen by the Director for Equality and Diversity (DE&D), a national expert in academic E&D issues and co-chair of the London Mathematical Society's Women in Mathematics Committee. The DE&D works with the School-level Athena Swan Self-Assessment Team and Equality and Diversity (E&D) Committee, with representation across departments, job families, levels and diversity characteristics.

Recruitment. Our recruitment reflects our commitment to equality and diversity. We shortlist all applicants with disabilities who meet the essential criteria for vacancies, all members of shortlisting and interview panels attend unconscious bias training, and interview panels cannot be single gender. Monitoring by gender and ethnicity is undertaken annually for recruitment (rates of application, shortlisting, offers and hires), research students (recruitment, numbers and completion times), management roles, uptake of staff training, promotions, internal and external funding applications, staff attrition, and applications for study leave. Where concerns are identified, action plans are prepared and implemented. For example, cognisant of the relatively low number of BAME staff in the MEC, our E3-CMC recruitment campaign used targeted Facebook advertisements to ensure that opportunities were seen by potential BAME applicants. This was successful: 19% of our appointments in the E3 recruitment round were from BAME backgrounds, compared to none in previous campaigns.

Supporting part-time colleagues. We are committed to supporting career pathways of part-time staff. Our success can be illustrated by the progression of, and leadership roles filled by, part-time colleagues. For example, during the assessment period, Gilmore (0.6fte) has been promoted from Senior Research Fellow to Reader to Professor, and Alcock (0.6fte) has been promoted to Reader and served as Head of Department.

Flexible and remote working. We facilitate flexible and remote working via three routes. First, all teaching staff are permitted to designate one hour per day where teaching cannot be timetabled, to facilitate caring responsibilities and support a healthier work-life balance. Second, to facilitate remote working, all staff and research students are offered the choice of a desktop computer or a laptop together with a docking station and screen for their office. Finally, our remote working portal permits staff to access all IT resources remotely.

Professional development. Staff and research students with caring responsibilities are supported by a carer's fund of up to £200 each year to support additional costs associated with conference attendance. An annual equality analysis of staff conference attendance is undertaken each year, and action plans drawn up if required. The School funds female staff in leadership roles to attend the Aurora Leadership Programme, which seeks to take positive action to address the under-representation of women in leadership positions in the sector. We also have a dedicated fund which supports staff or students to travel to UK diversity-related events.

Returning from leave. As noted above, we offer preferential access to university fellowships for staff returning from parental leave, a policy which also applies to those returning from significant periods of ill health. Where colleagues do not wish to apply for a full fellowship, they are entitled to a reduction in teaching duties to help re-establish their research agendas. Phased returns to work are available where recommended by the University Occupational Health and Wellbeing Service.

Protected characteristics. Recent redesigns of our buildings (including new ergonomic office furniture) have significantly improved access for people with disabilities and chronic health conditions. We run E&D events to highlight positive role models for staff and students. In our annual Women in Science lecture, eminent women academics give talks on both their research and their career histories. In 2018, our Pride in STEM showcase featured talks from LGBT+ academics about their research and careers. In 2019, we organised a Supporting Black Excellence event, including a panel discussion on the experience of black staff and students in the School.

Staff and research student wellbeing. All staff in management roles undertake training on preventing and dealing with bullying and harassment, and we trained two mental health first aiders who provide confidential support to colleagues. More widely, the University offers a range of support services to staff including Counselling, Occupational Health and a telephone/web-based Employee Assistance Programme.

2.5 E&D Issues in the Construction of this Submission

This REF submission was constructed following the University's Code of Practice. All colleagues were asked to nominate and self-assess potential outputs for inclusion. In line with our Responsible Metrics Policy, these were peer assessed for originality, significance and rigour by two members of the unit's REF team (3 women, 2 men). The team attended bespoke E&D training to raise awareness of potential bias in the selection process. To ensure that no outputs were missed, bibliometrics were used to identify plausible high-quality outputs that colleagues had not self-nominated, and the possibility of nominating these was raised with authors. Throughout our REF preparations, equality impact assessments (EIAs) were carried out to assess both institutional processes and our draft return, including outputs selected, against protected characteristics, and to monitor whether further action was required. EIAs confirmed no issues required attention.

Section 3. Income, infrastructure and facilities

3.1 Research Funding

Our three research themes are central to our research funding strategy. The themes provide a forum for generating ideas for proposals and putting together teams to work on particular

calls/projects. If expertise is required from across the themes, we create ad hoc research clusters.

The MEC's Research Coordinator (Inglis) and Centre Development Manager (CDM, Meredith) take responsibility for encouraging and supporting applications for external funding. Rigorous and supportive internal peer review is organised, and funding is allocated for pump-priming research and impact activity, totalling £30k in 2019/20. Typically this funds professional development or pilot studies required to demonstrate an approach's viability before submitting an external funding application. Some small investments have yielded significant returns: for example, Batchelor, Gilmore and Inglis used £360 to test a new experimental paradigm for investigating children's symbolic number acquisition, which formed the basis of a successful application to the Royal Society for £85.8k to extend this work. Early findings were published in the *Journal of Educational Psychology* and demonstrated that it may be more effective to introduce children to the meaning of Arabic numerals using consistent concrete representations, or abstract representations, rather than heterogeneous concrete representations, the current approach that dominates early number books.

Our strategy for generating research income has been highly successful: our research spend since 2014 has been £1.4m, a 61% increase on REF2014. On top of this growth, the £6.6m E3 investment (2019-2022) from Research England – a major and prestigious grant awarded following a competitive review process across all disciplines – represents an unprecedented investment in education research capacity and has transformed the MEC.

Our 2014 research strategy aimed to diversify our funding profile, in line with our interdisciplinary perspective on education research. This has been a success; since 2014 we have received grants from Action Medical Research, AQA, British Academy, British Council, ESRC, HEA, HEFCE, Leverhulme Trust, OUP, Nuffield Foundation, and the Royal Society. We mention three highlights.

- Batchelor's three-year ESRC Future Leaders Fellowship (2014-2017, £229k) focused on individual differences in the extent to which young children focus on the numerical aspects of their environment - their 'Spontaneous Focusing on Numerosity (SFON)' tendencies. She made a significant methodological contribution which allowed her to uncover why children with higher SFON tendencies tend to have higher levels of mathematics achievement (*Learning and Instruction*, 2015).
- Gilmore was awarded £420k by the Royal Society (2014-2022) for a fellowship to examine the role of executive function skills (working memory, inhibition, shifting) in mathematics learning and performance. This work included the first study to examine the role of executive functions in different components of arithmetic rather than simply overall achievement. This allowed the specific role of executive functions in learning mathematics to be better understood, leading to an influential publication (*Cognition*, 2017).
- Foster's 15-month ESRC Connections Grant (2019-2020, £49k) funded a collaboration with researchers at Tokyo Gakugei University. The aim was to produce a detailed comparison of the mathematics curricula in Japan and England. The grant funded collaborative exchanges in which the research team observed lessons in schools, conducted in-depth interviews with Japanese textbook publishers, and held intensive workshops with academics. This led to novel theoretical work on 'didactical devices' and curriculum coherence.

3.2 Organisational Infrastructure Supporting Research and Impact

Research development. The CDM manages our research funding strategy in collaboration with the Research Coordinator. She is tasked with identifying appropriate funding opportunities, disseminating them to colleagues, and facilitating the development of proposals by, for example, running sandpit events on particular topics and offering detailed feedback on draft proposals. Because the CDM works with only MEC staff, she has been able to develop an in-depth understanding of individuals' research ambitions, facilitating the provision of truly bespoke support.

We also draw on institutional-level support from the Research Development Team in the University's Research and Enterprise Office (REO), who assist with the costing and submission of applications, and post-award financial management. Significant support is provided for strategically important proposals. For example, a dedicated Research Development Manager was assigned to work with Gilmore and Inglis – for a day per week over six months – on their successful E3 application. She contributed to all aspects of the proposal, from conceptualisation to costing.

Researcher development. Five colleagues work across the REO and Doctoral College to support the training and skills development of research leaders via studentships and fellowships. Particular support is provided for Fellowship applications, a notable area of success for us.

Partnership and Impact development. The REO includes a team dedicated to supporting academic staff developing their non-academic networks. Support from this team has been critical to our success in the Midlands Graduate School ESRC collaborative studentship competition, where we have been awarded five studentships in collaboration with industrial partners, such as Oxford University Press and Times Tables Rock Stars. A team of 4.5fte REO staff provide contractual advice on research and impact projects, including the negotiation of legal agreements which underpin each of our ESRC collaborative studentships.

3.3 Operational Infrastructure Supporting Research and Impact

Since 2014, our research infrastructure has been transformed. Significant refurbishments have created new offices, social space and research laboratories. We now have five research laboratories, including space dedicated to eye tracking, child observation (including via a two-way mirror), and adult studies. The E3 grant has facilitated a substantial investment in our research equipment, with over £500k spent in 2020 alone. Highlights include state-of-the-art fixed and portable eye trackers (EyeLink 1000, Tobii Fusion and Tobii Glasses), high-spec devices to measure electrodermal and electrocardiogram activity, audiovisual recording devices, and class sets of laptops and tablets to facilitate school-based studies. Our eye-tracking equipment will open up new research possibilities, including extending our existing work on students' attention while reading textbooks, to exploring student attention during live lectures (using our new highly portable trackers).

To manage this expansion in our research facilities, we appointed a Technical Tutor, Patel, who oversees our equipment and supports staff and students in their use. During the development of our new laboratories, Patel conducted two formal surveys to understand the research needs of all staff and research students. The resulting decisions, coupled with the bespoke support that Patel provides, have ensured that all staff and research students can access the research infrastructure they require.

We also derive significant value from university-level facilities created via the University's CALIBRE research framework, and give two examples here. First, Graduate House provides a dedicated training suite for postgraduate researchers, which permits our research students to collaborate across the University. Strauss and Wege run institutional ReproducibiliTea Open Research events at Graduate House. Second, the Institute of Advanced Studies provides bespoke, flexible spaces in which international visitors to campus can be based during their visit. It hosts cross-campus seminars and informal gatherings, maximising the value of international visits.

Section 4. Collaboration and contribution to the research base, economy and society

4.1 Collaborations, Networks and Partnerships

An international reputation for excellence is a key aim of our research strategy, so we encourage international collaborations and have formal arrangements and support in place to facilitate them. We describe three.

First, we have a collaboration agreement with MatRIC (Agder), Norway's leading centre for research in undergraduate mathematics education. Jaworski sits on MatRIC's International Advisory Board, and three joint MEC/MatRIC conferences were held in Loughborough (2014-2016). Tangible outcomes include a successful application to the Erasmus+ scheme to create a pan-European network on university-level pedagogy, that also includes the Universities of Amsterdam, Masaryk and Borys Grinchenko Kyiv (2018-2021).

Second, we are a founder member, alongside KU Leuven, Athens, Turku, Trier, Ioannina, Western Macedonia and Freiburg, of the European Association for Research in Learning and Instruction (EARLI) Centre for Innovative Research (E-CIR) on conceptual change in mathematics learning (2017-2020). EARLI awards competitive funding to establish one centre per year. The E-CIR has facilitated staff exchanges and joint work, including an international-comparison of mathematics textbooks.

Third, the MEC was the UK's representative in the Research Foundation Flanders (FWO) funded network 'Developing Expertise in Learners' (2014-2018). Organised by KU Leuven, the network facilitates collaborations between leading research groups from across Europe and North America, including Ghent, Maastricht, Geneva, the Technical University of Munich, and Harvard. Specific outcomes included special issues in *ZDM Mathematics Education* and *Educational Studies in Mathematics* co-edited by colleagues at Leuven and Loughborough, and numerous joint symposia at EARLI conferences. The success of the network led to funding for another, 'Developing and Stimulating Competencies' (2019-2023), which organises annual themed meetings, staff/student exchanges, and methodological summer schools.

4.2 Interactions with Research Users and Beneficiaries

Our impact strategy emphasises the importance of interacting with research users and beneficiaries. During the assessment period, knowledge exchange projects have been developed in collaboration with the David & Jane Richards Family Foundation, OUP, Mathematics in Education and Industry, No More Marking Ltd, and Times Table Rock Stars.

In 2019 we strengthened our interactions with research users by setting up the innovative Loughborough University Mathematics Education Network (LUMEN), designed to support mathematics teachers in schools and colleges. The network provides members with a free, carefully sequenced series of research-based continuing professional development events across each year, with remote support between sessions. To date, 111 secondary teachers have joined the network, and we will expand further post-pandemic.

4.3 Wider Contributions to Society

Our impact strategy has resulted in significant contributions to society in addition to those demonstrated in our impact case studies. For example, a series of projects funded by Action Medical Research and the Nuffield Foundation investigated the educational difficulties for children born very preterm, and developed resources to support primary schools. These are now freely available online, have been promoted by the DfE, NHS and Association of Educational Psychologists, and were used by 14,041 unique users (42% teachers, 21% parents, 13% health professionals) from 58 countries in the 19 months since launch.

During the assessment period, several outputs have received widespread media attention. For example, Jones and Inglis's article, "Fifty Years of A-Level Mathematics", used comparative judgement techniques to assess changes in examination standards over time. The findings were reported in outlets including the *Independent*, *Telegraph, Times*, and *BBC News.*

4.4 Contributions to the Sustainability of the Discipline

Contributing to mathematics education as a discipline is one of our strategic priorities. We therefore encourage staff to take leadership roles in learned societies and funding bodies, especially where these involve international leadership or national priorities. A particularly notable example was Jaworski's term as President of the International Group for Research in the

Psychology of Mathematics Education (PME, 2013-2016), the field's largest international research organisation.

4.5 Indicators of Wider Influence

Our overall strategy during the assessment period has been to conduct research in mathematics education that achieves the highest levels of international excellence and recognition. Our success can be seen by influence we have had on the field, evidenced by invitations to take up editorial roles, keynotes, fellowships and prizes.

***Editorial board roles*.** During the assessment period, MEC staff have served in numerous editorial roles. The *International Journal of Mathematical Education in Science and Technology* has been edited from Loughborough since its foundation in 1970. Colleagues have served on the editorial boards of the leading mathematics education journals (*Educational Studies in Mathematics, Journal for Research in Mathematics Education*) as well as numerous other education and psychology journals (*Developmental Science*, *For the Learning of Mathematics*, *Journal of Cognitive Psychology*, *Quarterly Journal of Experimental Psychology, Research in Mathematics Education*).

Invited keynotes and lectures. During the assessment period colleagues in this return have given a total of 93 international invited lectures, a near 300% increase on REF2014. Highlights include Gilmore's keynote at the Royal Swedish Academy of Sciences (Stockholm, 2017), Inglis's keynote at the 18th Annual Conference on Research on Undergraduate Mathematics Education (Pittsburgh, 2015), and Jaworski's keynotes at the Conference of the Mathematics Education Research Group of Australasia (Sydney, 2014) and the Didactics and Epistemology of Mathematics (DEMIPS) conference (Montpellier, 2018).

Fellowships and prizes. Five Royal Society, British Academy and ESRC fellowships have been held by MEC colleagues during the assessment period. Colleagues have won numerous awards in recognition of their outstanding contributions, demonstrating the substantial influence our unit has had on mathematics education. Alongside Gilmore's EPS Prize (2020), and Inglis's Selden Prize (2014) and THE Outstanding Supervisor Award (2017), colleagues' research and impact work has been recognised via three additional prestigious awards:

- Gilmore's *Pediatric Research* article "Nature and origins of mathematics difficulties in very preterm children: a different etiology than developmental dyscalculia" received the 2015 British Psychological Society's Neil O'Connor Award, which honours research on cognitive disorders that appear in development and persist throughout life.
- Jones and Inglis's article "Fifty years of A-level mathematics" received the 2017 *British Educational Research Journal*'s Editors' Choice Award for the strongest contribution published in the journal in the previous year.

In 2016, Croft was awarded the Institute of Mathematics and its Applications' Gold Medal, which recognises "outstanding contributions to mathematics and its applications over a period of years", for the impact of his research on mathematics support. This was the only time in the award's history that it had been given to an education academic rather than a mathematician.