

<b>Institution: The Open University</b>
<b>Unit of Assessment: UOA10 Mathematical sciences</b>
<p><b>1. Unit context and structure, research and impact strategy</b></p> <p><b>Context and structure</b></p> <p>The Open University (OU) supports a lively and stimulating mathematical sciences community based in the School of Mathematics and Statistics, one of six Schools in the Science, Technology, Engineering and Mathematics (STEM) Faculty. Work submitted to this REF is in the following broad areas:</p> <p>Combinatorics and model theory: <b>Barbina, Brignall, Širáň, Webb</b></p> <p>Real and complex dynamics: <b>Clark, Mestel, O’Neil, Rippon, Short, Stallard</b></p> <p>Symbolic dynamics and aperiodic order: <b>Grimm, Rust, Yassawi</b></p> <p>Applied mathematics and theoretical physics: <b>Pradas, Rogers, Umerski, Upton</b></p> <p>Statistics: <b>Adhikari, Elfadaly, Faria, Garthwaite, Trendafilov</b></p> <p>History of mathematics: <b>Barrow-Green</b></p> <p>These 23 staff (22.11FTE) comprise 6 professors, 1 reader, 8 senior lecturers, 7 lecturers and 1 research fellow (6 female, 17 male, 3 BAME and 3 ECR). Some staff work in more than one area; for example, <b>Grimm</b> and <b>Mestel</b> in applied mathematics, and <b>Short</b> in symbolic dynamics.</p> <p>All but two of the staff above are ‘central academics’ with contracts that involve research and teaching. The remaining two, <b>Barbina</b> and <b>Rogers</b>, are ‘regional academics’ with contracts that mainly involve teaching and management responsibilities, who have been given time and dedicated support by the School to pursue their research.</p> <p>There is a vibrant group of 18 PGR students, 10 being full-time (3 female, 7 male) and 8 being part-time (5 female, 3 male), and 4 PDRAs (1 female, 3 male), at the census date.</p> <p>In addition to the submitted staff listed above, <b>Critchley, Farrington, Jones, McConway</b> and <b>Whitaker</b> (statistics), <b>Gray</b> (history of mathematics), and <b>Wilkinson</b> (theoretical physics) worked in the School during this REF period, but were not employed at the OU on the census date. They all made major contributions to the research environment and many of their research-related achievements appear in Section 4.</p> <p>The School also has a strong group in mathematics education (submitted to C23).</p> <p><b>Achievement of strategic aims</b></p> <p>At the start of this REF period, our overall aim was to build on our strengths in complex dynamics, combinatorics, history of mathematics, aperiodic order and, medical statistics, and to strengthen applied mathematics by new recruitment. We describe the key successes we achieved in this period in relation to four strategic aims.</p> <ol style="list-style-type: none"> <li>1. <u>Build on strengths through targeted recruitment and bidding</u> <ol style="list-style-type: none"> <li>a) The most notable success has been the formation of a major group in dynamical systems working across the spectrum of pure and applied mathematics, bringing together researchers from our world-leading groups in real and complex dynamics, and symbolic</li> </ol> </li> </ol>

dynamics and aperiodic order.

Our actions have led to a critical mass of researchers in this area; enabling the formation of a fortnightly dynamical systems seminar series (currently online) and two regular discussion groups which include researchers from Bielefeld, Bristol, Glasgow, Nottingham and other institutions. This has encouraged cross-fertilisation of ideas and provided a platform for large-scale collaboration.

The group was formed as a result of excellent new appointments of staff and successful bids to fund PDRAs:

- In 2019 we appointed **Yassawi** (symbolic dynamics and automata), whose areas of expertise are close to those of **Grimm** and also **Short**.
- In 2020 we further strengthened expertise in symbolic dynamics with the appointment of **Rust**.
- **Rippon** and **Stallard** continued their strong track record of bidding for grants, leading to another EPSRC funded PDRA in complex dynamics in the REF period.
- **Grimm** bid successfully to EPSRC for a PDRA in aperiodic order.
- The OU supported the growth of this group by funding a research fellow in complex dynamics (**Clark**).

The group continues to grow from strength to strength and will be joined in 2021 by a DAAD funded PDRA from Germany, and by two further PDRAs funded by **Grimm's** New Horizons EPSRC grant and **Yassawi's** New Investigator Award from EPSRC.

- b) The applied mathematics group was strengthened by the appointment of **Pradas** (theoretical physics, especially fluid dynamics) in 2014, to build on **Wilkinson's** highly successful work in this area. His research has flourished at the OU with outstanding publications (including with **Wilkinson**), significant potential for industrial impact, and a successful EPSRC first grant to fund a PDRA, all of which contributed to his promotion to SL in 2018.
- c) Our highly successful group in statistics, with particular strengths in applications (underlying two of our impact case studies), is undergoing a period of regeneration, building on its reputation – with new appointments of **Elfadaly** (multinomial models) and **Adhikari** (statistical genetics) who are producing excellent outputs and attracting high quality PhD students. In 2019 the OU supported these new appointments by funding a research fellow to work with **Adhikari** – the fellow moved to a permanent position in 2020.

In 2020 we were delighted to appoint a new statistics chair **Biedermann** (design of experiments and medical statistics), whose current research-related activities include membership of the College of Experts for the DHSC/UKRI COVID-19 Rapid Response Rolling Call, and Associate Editor for JRSS, Series B. **Biedermann** is Co-I on a recent EPSRC grant with a collaborator in Cardiff, and is making new links with colleagues in other parts of the STEM Faculty. She is not included in this submission as her start date was after the census date, but she will be a key player providing research leadership to the statistics group over the next REF period.

- d) The combinatorics and model theory group has continued to flourish with an emphasis on pursuing external funding opportunities. **Webb** successfully bid to EPSRC for funding to support an extended visit to the University of Queensland, also funded partly by an Ethel Raybould Visiting Fellowship there, and **Barbina** received Santander funding for a visit to the University of Barcelona. **Brignall** submitted three bids to EPSRC, receiving positive feedback, with the most recent supported for funding but just missing the threshold. This provides a strong platform for future bids.

2. Develop our community of PGR students

- a) Over the period we have been successful in recruiting an increasing number of high-quality PGR students, partly through encouraging applications from high-performing students on our *MSc in Mathematics* programme, which has around 500 students.
- b) For several years we have made the case to EPSRC for DTP funding, recently successfully, enabling us to recruit a larger than usual cohort of PGR students in 2021.
- c) Recruitment of PGR students has been particularly successful in dynamical systems and combinatorics, providing critical mass for a new seminar series in discrete mathematics (currently online) modelled on the successful dynamical systems seminar mentioned earlier.
- d) Our PGR students are encouraged to participate in a range of activities that will support their career development; for example, they organised 8 externally funded conferences during the REF period. Of the 24 students who graduated in the REF period, 13 have gone on to university positions, with one combinatorics student securing a permanent lectureship within 18 months of graduating.

3. Embed public engagement within research

The School has an outstanding record in public engagement (described in Section 4) which we have built on in this period, introducing a number of actions that have enabled us to achieve significant public engagement with our research.

- a) The School has introduced an Engagement Lead to co-ordinate and champion public engagement. Her work with staff bidding for grants has ensured that outreach is embedded within the application – this has been particularly successful in **Pradas'** EPSRC funded project. There are now a number of successful researchers (most notably **Adhikari, Barrow-Green, Grimm, Pradas** and **Short**) who are highly active in this area.
- b) **Barrow-Green** has built on her international profile as a historian of mathematics and demonstrated the importance of a historical viewpoint in public engagement. This has led to invitations to play a leading role in numerous national initiatives, including the new maths gallery at the Science Museum. Her work in this area has been recognised externally (for example with the *Chandler Davis Prize for Expository Excellence*) and forms the basis for one of our impact case studies.
- c) The ability to contribute to public engagement activities is now considered during recruitment. One of our recent statistics appointments **Adhikari** has a rapidly growing record in this area; for example, he is now a consultant on Radio 4's *More or Less*, an OU-BBC collaboration which has played a key role in informing the public during the Covid pandemic (current audience figures are around 2.5 million per week).
- d) Our PGR students and PDRAs are now actively encouraged to participate in outreach activities as part of their training. Notable successes include one of our history of maths students playing a key role at the launch of the Bank of Scotland's new £10 note, featuring Mary Somerville, the topic of her thesis, and several dynamical systems students participating in an exhibition at the Science Museum.
- e) **Chicot** (a regional academic) was given a secondment from the School to be CEO of *MathsWorldUK* in 2018-19, during which she led a campaign to support this new museum, obtaining, for example, grants totalling £160K for a national touring exhibition (including exhibits based on **Grimm's** quasicrystals research) and a pledge of £1.3 million from the Simon Norton Foundation; see <http://mathsworlduk.com/wp-content/uploads/2019/07/Newsletter-No5.pdf>.

4. Champion the strength of diversity

The School has embedded equality and diversity throughout its activities and supported staff to lead work nationally in this area.

a) **Barrow-Green** has led research on the history of women in mathematics attracting numerous international invitations to speak, described in more detail in the impact case study. Her PGR and PDRA are also highly active in this area.

b) **Stallard** has continued to play a leading role at national level championing good practice to support the careers of women in mathematics, through the LMS and now as a Diversity Champion for the EPSRC Mathematical Sciences SAT. Her work was recognised by an OBE and a *Suffrage Science Award* from the MRC.

c) The School has recruited and promoted excellent female staff and, at the date of submission, has a professoriate that is 50% female.

**Strategic aims for future research**

Our overarching vision for the future is to sustain our lively, outward-looking collegial research environment, with world-leading research in several key areas, to seek opportunities for growth in these areas, in particular in PGR student numbers and external income, and to support the OU's mission 'to inform, inspire and influence' through research-informed undergraduate and postgraduate teaching, and outreach.

We have the following specific strategic aims for the next period.

1. Build on critical mass to form multi-institutional partnerships

In the current period we have achieved a critical mass of highly regarded researchers in the broad area of dynamical systems. This provides a strong platform from which we can bid for larger scale grants in collaboration with other institutions; we will explore opportunities such as CDT Funding, Network Grants and Programme Grants.

2. Develop new interdisciplinary collaborations

Within our statistics group, **Biedermann** will lead on establishing further interdisciplinary collaborations within the OU and with industry. A key strategic aim is to exploit funding opportunities, e.g. from the EPSRC or the MRC/NIHR, to recruit PDRAs to increase our research capacity and to train the next generation of research statisticians. Having a vibrant research community in statistics will also contribute to a lively and stimulating environment for our PGR students.

The additional income achieved through collaboration on interdisciplinary grants, together with additional income from our successful new degree programme in data science and the planned development of microcredentials in statistics, will enable us to expand the range and scope of our research activities through further new academic appointments.

3. Build on our strong track record in public engagement and equality and diversity

Building on **Barrow-Green's** expertise, the School has plans to produce a major online resource (on *OpenLearn*, the OU's free virtual learning platform with over 10 million visitors per annum) describing the rich diversity of mathematical contributions historically of under-represented groups in the UK and internationally, designed to be of long-term value to all university mathematics departments. This project will also lead to new research outcomes.

#### 4. Develop scholarship into high quality educational research

Within the current period, the School has been at the forefront of OU initiatives to underpin teaching with rigorous scholarship, and sharing good practice nationally. For example, **Hilliam** (statistics group) was one of the founders of TALMO (Teaching and Learning Mathematics Online) and was recently appointed as Vice President (Professional Affairs) of the RSS, and **Lowe** (applied mathematics group) has made key contributions to the development and analysis of the computer marked assignment system STACK, pioneered by Sangwin (Edinburgh), and recognised by an HEA *Collaborative Award for Teaching Excellence* (OU, Edinburgh, Loughborough).

With input from our recent appointments in mathematics education, we are now in a strong position to produce high quality educational research with high impact.

### Strategy for impact

The School encourages all staff to explore potential impact arising from their research – for example, through presentations at School meetings and discussions with new members of staff. The School's Impact Lead works closely with the REF Lead, contacting all staff on a regular basis and exploring progress on impact – providing support and suggesting ways in which this could develop.

Staff are encouraged to collaborate with others, both in other disciplines and in industry, to provide mathematical solutions to real-life challenges. Practical support is offered in the form of funding – for example, to visit experimentalists – and potential impact is one factor taken into consideration when allocating studentships. Several examples of potential impact of this type, that are currently being supported, are given below.

As mentioned above, staff are encouraged to take advantage of the extensive networking and training opportunities for outreach – for example with the BBC and the Royal Institution - facilitated by our Engagement Lead. We have identified particularly strong potential in a case of this type, given at the end of the list below.

In addition to the examples given below, many of our staff are developing links with other Schools and fostering opportunities for new collaborations with potential impact, and there are further opportunities for impact arising from our developing educational research.

#### 1. Forecasting structural movements in dams – Faria

**Faria's** statistical expertise played a key role in the development of the technology used in Brazil by IntellTech's *Geo Inspector* system to statistically forecast and thus anticipate short and medium-term structural movements of dams, which may cause accidents. The technology uses results from a paper co-authored by Faria in 2016. The *Geo Inspector* system was installed at several dams operated by the Samarco mining company, following serious accidents at other dams in Brazil resulting in over 300 deaths.

To facilitate future developments, the School encouraged and funded **Faria** to visit IntellTech in 2019. As a result, he is now working with Dr Luiz Teixeira, the CEO of IntellTech, to improve yet further the statistical detection system in *Geo Inspector* by taking account of further variable geological parameters. Letters from Vale and Samarco in 2020 confirmed that the IntellTech system uses the results of **Faria's** 2016 paper for 'forecasting and prevention of geotechnical structural movements and mitigation of geotechnical risks'.

## 2. Impacts on hard disk technology – Umerski

**Umerski's** earlier work was highly influential on the development of hard disk technology – see his article in [UK Success Stories in Industrial Mathematics, Springer, pp. 179-204, ISBN-10: 3319254529](#). More recently there have been two further developments which have significant potential in relation to computer memory storage.

First, there has been experimental verification ([Phys. Rev. B 94, 245415 \(2016\)](#)) of a phenomenon predicted by **Umerski**, Autes and Mathon ([Phys. Rev. Lett. 104 217202 \(2010\)](#)) which has major potential for enhancing the performance of hard disks and magnetic sensors.

Second, building on his 1990's work on Interlayer Exchange Coupling, **Umerski** has demonstrated an ultra low-power mechanism for switching the direction of mesoscopic magnetic moments ([arXiv: 1709.09525](#)), and is pressing experimentalists to confirm these new ideas. This would overcome a fundamental obstacle to the development of Magnetic Random Access Memory, a principal contender for the next generation of computer memory devices.

## 3. Novel superior materials based on aperiodic tilings – Grimm

**Grimm's** recently awarded EPSRC New Horizons grant will employ a PDRA to work on a project with colleagues from the OU's School of Engineering and Innovation to investigate the possibility of using ideas from aperiodic tilings and quasicrystals to produce smart materials. This is an exciting project which received funding in this highly competitive call, and which offers a variety of potential applications, for instance, to reliable and cheap production of bespoke orthopaedic implants, space and aerospace components.

## 4. Microfluidics – Pradas

**Pradas'** research is on interfacial fluid mechanics and has applications to microfluidics, droplet transport, and heat/mass transfer industrial units. His work is often part of projects involving industrial partners, such as heat exchangers company Alfa Laval, microfluidic chip manufacturers Dolomite and Arrayjet. An outcome of his EPSRC funded New Investigator Award has been the development of new strategies for controlling droplets on solid surfaces. He is currently working with The University of Edinburgh to exploit these ideas for applications using droplet-based microfluidic devices, such as heat-removal systems used in micro-processes, and they are in contact with Jaguar Land Rover, for applications in self-cleaning surfaces.

## 5. Superoscillatory imaging – Rogers

**Rogers** works on superoscillations with the world-leading team at Southampton, providing mathematical theory to enable technological advances, as described in her recent extensive [review article in Journal of Physics: Photonics](#). There are many potential technological applications, from optical and electron microscopy, to nanofabrication with light, and next generation hard disks. The Southampton team hold three granted patents on the technologies for superoscillatory imaging and are developing a network of industrial collaborators, including microscope manufacturers working in Nikon, Leica, Zeiss and Oxford Nano-imaging.

## 6. Energy forecasting – Mestel

**Mestel**, in collaboration with Nuttall from the OU's School of Engineering and Innovation, works on issues involving the sustainability of energy supplies. Their work with an OU PGR student concerning the future investment in energy generation on the island of São Miguel in the Azores used System Dynamics to reach conclusions about the most effective policies to achieve the highest possible usage of renewables, and was published in [Technological Forecasting and Social Change](#). Both this and the work of a current PGR student, modelling the GB energy grid to study the occurrence of adverse 'events', are expected to make a very real impact on the future plans of energy providers.

## 7. Outreach based on statistical genetics – Adhikari

**Adhikari**, one of our recent appointments in statistics, is developing considerable public engagement with his research into statistical genetics; this research has helped to identify the genetic origins of various features of the human body such as ‘hair traits’ and ‘nose shapes’. He has papers on this in *Nature Communications* and his work was featured in the BBC Radio 1 Stories episode *Beauty DNA+* (2018).

**Adhikari**'s work is featured in the video <https://youtu.be/XmV9hAwcvZ4> which has over 23k views. The video was produced by the science-based media charity *Think media*, who make educational YouTube videos in English and Bengali for viewers in Bangladesh, India, and other countries, including Bengali speakers in the UK, with the aim of improving the educational attainment of the UK-based Bangladeshi-origin communities. **Adhikari** is a scientific advisor for the charity.

## 2. People

### Equality and Diversity

The School prides itself on providing a supportive and inclusive environment with good practice around equality and diversity at the heart of all the policies described in this section. The School's Athena SWAN Committee is currently preparing a submission for a Silver Award (for November 2021), having built on the many initiatives that were praised when its Bronze award was renewed in 2017.

The Athena SWAN Committee is chaired by **Stallard** who is also Deputy Head of School and Chair of the School Promotion Group. The Athena SWAN Action Plan contains key sections on staffing, career development and PGR students, led by members of the School Management Team. The Committee has extended its remit to consider diversity more widely than gender and, in January 2021, formally became the EDI Committee. Membership includes a PDRA and a PGR student.

The table below shows the composition of staff in our submission.

	Female	Male	%Female
Professor	2	4	33%
Senior Lecturer	2	7	22%
Lecturer	2	5	29%
Research Fellow	0	1	0%

*Table 1: Composition of academic and research staff submitted to REF2021*

The proportion of female academic staff in the submission is above the national average in mathematical sciences (~22% overall), particularly at professorial level. Since the REF census date, a retiring male professor has been replaced by a female appointment so that 50% of our professors are now female.

The B10 submission followed the OU's Code of Practice for REF2021 in relation to equality and diversity and members of the B10 Panel all undertook EDI training before grading outputs. The balance of the outputs submitted which emerged from our grading system is summarised in the following table, and we feel this gives a fair representation of research contributions amongst the submitted staff.

	Total	Female	BAME	ECR	Former
Staff	23	6 (26%)	3 (13%)	3 (13%)	3 (13%)
Outputs	50	14 (28%)	6 (12%)	5 (10%)	4 (8%)

Table 2: Submitted outputs by category: gender, BAME, ECR and former staff

### Recruitment strategy

The School is currently undergoing a period of regeneration with the STEM Faculty supporting requests for posts to be released ahead of retirements in order to ensure continuity. A number of excellent appointments have been made in 2019/20. The priority has been to develop our applied mathematics group and to rebuild our statistics group following several retirements, in addition to regenerating our mathematics education group.

The School is committed to maintaining its world leading role in the history of mathematics and in dynamical systems, and to further developing the statistics group. For other vacancies, the aim is to advertise broadly to recruit the strongest possible candidates who can interact with groups of strength within the School such as combinatorics and fluid dynamics.

The nature of OU work means that we require academics to have the ability to produce excellent written teaching material in addition to excellent research, and both are tested at interview. We also place importance on the ability to work as part of a team and to contribute to the wider life of the School such as our successful public engagement activities.

As part of our Athena SWAN work we have introduced a range of policies around recruitment. The initiative to invite a diverse range of seminar speakers to enable us to make contact with possible future members of staff has been particularly successful. We have consistently exceeded our target of 25% female for the gender balance of speakers and have encouraged staff to think about diversity more widely when inviting speakers. This action contributed to our success in appointing **Yassawi** (F). Another excellent female seminar speaker was encouraged and supported to submit an application for an LMS Early Career Fellowship to be held at the OU, which was successful. She has subsequently been appointed to a permanent lectureship at Derby and retains close links with our dynamical systems group.

We have also produced a guide for appointing PDRAs to ensure that good practice is followed by all appointment panels. This guide has been identified as an example of good practice for other Schools. Three EPSRC funded PDRAs were appointed in the period, **Evdoridou** (F), **Haynes** (M) and **Nagai** (M), who are closely integrated within the academic and social life of the School.

All panels include both men and women, essential criteria are carefully reviewed to be as minimal, inclusive and clear as possible, and wording for adverts and further particulars is agreed with the Athena SWAN Chair, with adverts appearing in 'women in maths' mailing lists. All panel chairs have undergone training in recruitment and the School organised a session on unconscious bias led by Advance HE, with very positive feedback from staff.

Two excellent appointments were made early in the period, **Pradas** (M) in applied mathematics, and **Elfadaly** (M) in statistics. A drive for recruitment in 2019 led to three further appointments, **Adhikari** (M) and **Hilliam** (F) in statistics, and **Yassawi** (F) in applied mathematics. The diversity of these five appointments is notable with 40% female and 60% BAME.

The School has also regenerated its mathematics education group (submitted to UOA C23), appointing Dame Celia Hoyle as a consultant to review the group and make recommendations on future directions. As a result we were able to make two excellent appointments at SL level and to make one temporary member of staff permanent. This group is raising the quality of



educational research and impact across the School, with strong potential for future B10 submissions.

We have also appointed several regional academics, one of whom is research active (**Rogers (F)**) and, as mentioned earlier, the School has arranged for her to have additional research time.

Almost all Category A staff are on permanent contracts, with just two of the submitted staff on fixed-term contracts: **Rust (M)** was appointed to support applied mathematics through a period in which two staff have senior leadership roles in the School, and **Clark (M)** as a research fellow.

### Career Development

All new members of staff, *including PDRAs*, receive an extensive induction, meeting key members of staff and undergoing training involving a series of online modules, including some related to equality and diversity. They are allocated a mentor and a probation advisor. They are also prioritised for internally funded PhD studentships and given a lighter teaching load for their first few years in order to establish their research careers, and to encourage grant applications.

The School has an annual cycle of meetings to ensure that the career development of all academic staff, including PDRAs, is considered carefully.

- In October, several members of the School's Management Team (including the Athena SWAN Chair) meet with all appraisers to review the CVs of all non-professorial members of the School. This group provides feedback (via appraisers) for all staff on readiness for promotion and areas to be developed, with suggestions of academic and professional development opportunities, including leadership roles.
- The School Promotion Group then meets and allocates mentors to all staff identified as having a potential for promotion to SL in the next couple of years or to Chair over a longer period. Cases for promotion are developed in collaboration with the mentor and can include a special circumstances form (e.g. for part-time working).
- In May all staff receive an appraisal at which the previous year is reviewed and objectives are set for the following year, taking the feedback from the CV review group into account. The School has a 100% uptake for appraisals.
- In June, the CV review group meets again to identify staff, *including PDRAs*, whose work deserves recognition by an award or additional increment.

Promotions within the period include **Barrow-Green** to Chair and **Brignall, Short** and **Pradas** to SL, the latter three all taking on leadership roles and with strong potential for promotion to chair in the future.

The gender balance of committees and leadership roles are carefully monitored to ensure they reflect the balance of the School; for example the School's REF Panel is 36%F. As part of its Athena SWAN work, the School has introduced a new system of transparent workload planning and a list of management roles and deputies, mostly with three year terms to provide a good balance of continuity and opportunity for development. All key roles are advertised and staff are encouraged to apply, especially when this would be a good fit for their career development. The School has also introduced a well-attended seminar series (currently online) covering a wide range of topics to support Academic and Professional development.

All central academics have a study leave allowance, as described in the OU's Institutional Environment Statement. One focus for the School has been to support the career development of our regional academics who have limited time available for research. We have provided funding to cover some regional duties of staff to enable study leave to be taken more easily and are delighted that this has enabled two regional academics (**Barbina**, recently promoted to SL, and **Rogers**) to pursue successful research projects. Many others have developed innovative scholarship projects.

The School has a generous budget to support research, outreach and career development more generally (£60k for research in 2020/21), and requests for research funding are almost always approved. New members of staff, those who have bid externally for grants, and those returning from extended leave (such as parental leave) or heavy managerial duties are encouraged to use a higher level of funding per annum, and given reduced teaching loads where possible. Additional caring costs can be claimed alongside travel and subsistence.

The Research Director has produced a research wiki which gives helpful advice on a range of topics including: applying for grants (see Section 3), recruitment and supervision of PGR students, and financial support available from the School.

### **Flexible working and staff wellbeing**

The School has put several actions in place to support remote working – pre-Covid, most regional academics were home workers with central academics typically working on campus for at least three days a week. Meeting rooms and the School seminar room were set up with equipment to enable remote participants to join in easily and staff were trained in using the equipment and in chairing meetings to ensure that remote participants are fully included. This experience enabled a rapid transition to homeworking for all during the pandemic.

The University has an agile working policy and many staff in the School have at times requested (and been given) periods of part-time working, for example after maternity leave. We have introduced increased support for staff on parental leave – most recently, a fixed term appointment was made to cover time during and after a maternity leave in the maths education group – with two staff being appointed as a job share. Staff take their full paternity leave, with arrangements made to cover duties. During 2020/21, the University has generous contingency leave arrangements in place, ensuring that all staff can take additional leave for reasons such as childcare. This option was encouraged by the Head of School and used by several members of the School.

The School has a ‘good practice guide’ for emails and meetings, with staff wellbeing in mind, and a core hours policy for meetings of 10-4, Monday to Thursday – to support those with caring responsibilities and to create quiet time for research and scholarship.

The Athena SWAN group organises regular tea and cake sessions to encourage staff, PDRAs and PGR students to meet informally (currently online!). Since Covid, each group has introduced weekly informal meetings for chat about work and home life, and there are weekly coffee drop-in sessions for the whole School. Group leads and appraisers keep in regular touch with the staff that they support, and the Postgraduate Tutor and third-party monitors support PGR students.

### **PGR students**

The School supports a vibrant community of PGR students, both full-time and part-time, with a successful programme of promoting high quality research, employability, enrichment, and comradeship. Most full-time students are supported by University three-year studentships (the School usually has two per year), with several EPSRC studentships available in 2020-22, resulting from the School’s and OU’s recent success in obtaining EPSRC funding. Part-time students are mainly self-funded, and expected to complete their studies in 6-8 years.

Annual advertising of our PGR studentships and part-time PhD programme includes wording that encourages women to apply. Also, female applicants are put in touch with female staff, for example over lunch if they visit the School, and interview panels for female applicants include at least one female member.

There is huge diversity to our PGR population, in academic background, age, ethnicity, gender, nationality, and personal objectives. To support the multiplicity of needs that this diversity brings,

we have a development programme for supporting and monitoring students, which includes six-monthly reports, and a probation report and mini-viva at the end of their first year.

The supervisory team for each PGR student comprises two or more active researchers, at least one of whom must be an experienced supervisor. The student is also assigned a third-party monitor, for independent counsel. For female students, at least one member of this team is female. All the students are overseen by and known personally to the School's Postgraduate Tutor who leads on postgraduate recruitment and development, ensuring that good practice is followed at all stages.

Students are offered guidance from the School on how to make the most of their study time (again details appear on the research wiki), and they can participate in many development opportunities provided by the University, either in person or remotely. Full-time students are given ample office space (typically 4 students per office) and a travel allowance of £1250 per annum. All students are encouraged to join a learned society, with the School paying their membership fees for three years. Crucially, postgraduate students are encouraged to feel that they are an integral part of the School, helping shape the way we research, teach, and engage with the wider community.

The School's employability framework for PGR students encourages students to augment their research portfolios by making grant applications, organising conferences, and establishing independent external research collaborations. For example, in the REF period our PGRs organised 8 externally funded conferences, and 2 students used Santander funding to make research visits (one to Kyoto and the other to Madrid), which led to fruitful collaborations, including a joint paper in Proc LMS for one of them.

PGR students are encouraged to enrich their PhD degrees with education, teaching, and outreach activities and the School has developed several significant opportunities for this. For example, the School is an active member of the *London Taught Course Centre* and the *Academy for PhD Training in Statistics*, and students benefit greatly from participating in the lecture courses offered by these groups, alongside students from other universities.

One current PDRA gave a lecture course at the LTCC in 2019, and she (together with another of our former PDRAs) gave an online course aimed at PGR students in late 2020, funded by the LMS, with about 100 international participants.

Students are also encouraged to deliver research lectures themselves, at conferences, in our graduate seminar series (organised by PGR students and PDRAs, and now online), and at one of the two PGR Student Days held annually within the School. In the REF period, 4 of our PGR students won prizes for talks and posters at conferences such as the BMC/BAMC, YRM and LMS Graduate Student Meetings.

Students have diverse opportunities for teaching experience by, for example, delivering online tutorials or lectures, creating screencasts, talks at MSc residential weekends, and marking examinations. PGR students also play a key part in the School's public engagement programme (described in Section 4), contributing energy, enthusiasm and innovation – they are outstanding ambassadors for their subject and the University.

During the REF period, 24 PGR students in mathematics and statistics graduated, 4 of whom were part-time, and only 2 registered students withdrew. Since 31 July 2020, 3 further PGR students have graduated, all of whom might have graduated by that date if the Covid lockdown had not occurred.

The success of the School's PGR programme is evidenced by the fact that in the REF period 13 students secured university positions following their PhD graduation, for example, at Kyoto University (with a Royal Society-JSPS Fellowship), Polish Academy of Sciences, University of Barcelona, Umeå University, Oxford, Strathclyde, Liverpool, Nottingham and QMUL.

### 3. Income, infrastructure and facilities

#### Infrastructure

The School of Mathematics and Statistics occupies two floors of the Alan Turing Building on the OU's central campus in Milton Keynes. Members of staff have good working conditions, mainly individual offices with good levels of equipment. PGR students are in spacious offices with 4-5 students per office, and PDRAs share with at most one other. There is a well-used common room area and a seminar room suitable for up to about thirty people, both having blackboards and whiteboards. This facilitates our regular seminar programmes of external speakers in mathematics and in statistics, and internal seminars, for example in dynamical systems.

The seminar room has been equipped for many years with digital projectors and audio-visual equipment suitable for online synchronous or asynchronous broadcast, so seminars can be delivered remotely, originally using *Skype for Business* and now *Teams*. These systems were upgraded in 2018 and the high-quality equipment is readily available for research uses where appropriate, and for interviewing prospective PGR students, PDRAs and other academic staff. Since March 2020, all our seminar series have continued online, generally with much larger attendance, often including 'visitors' from other universities.

Staff and students have access to the extensive facilities of a modern research library, with most key mathematics and statistics online journals and databases available via the University network and a large, up-to-date collection of books and reference works. They also have access to all the mathematical and statistical software packages they require. The University has a parallel computing facility with more than 750 CPU's and 2.8TB of RAM that is used exclusively to support STEM research, including several projects of staff and students within the School. In particular this supports work with potential impact led by **Grimm**, **Pradas** and **Umerski**.

#### Research income

Researchers in the School are encouraged and supported to pursue a broad range of funding opportunities. We have been increasingly successful recently, most notably with bids to EPSRC. There have also been many successful smaller bids, for example to the LMS, and several applications have been made for funding from ERC and Leverhulme.

At appraisal, staff discuss possible ideas for grant applications. Proposals are taken to a group leader, who allocates time in the applicant's workload for grant writing. In the interest of openness, the process is organised by the Director of Research, who also arranges grant-writing workshops.

Our STEM Research, Enterprise and Scholarship team of 15 staff support the development and management of external bids (and PGR student administration) and the STEM Impact Manager helps develop pathways to impact in funding bids and supports progression and communication of impact for awarded projects.

Each applicant is supported by a mentor (or mentors) at all stages, including the reviewer feedback stage. As examples, our recent applied mathematics appointments **Pradas** (M) and **Yassawi** (F) were mentored by **Stallard**, who has been PI on four successful EPSRC bids since 2009. **Pradas** obtained an EPSRC New Investigator Award in 2018, and **Yassawi** bid successfully for the same award in 2020; both bids were for PDRAs.

The income profile for the beginning of this period reflects our award success in the latter part of the previous period. Staffing departures, in particular in statistics, affected the profile in the middle of this period, but it is now on a steep upwards trajectory, and the recent appointments will enable us to strengthen our income portfolio further.

In particular, our new professor of statistics, **Biedermann**, has an excellent record of securing research funding (including a success as Co-I with EPSRC in December 2020), and her experience on UKRI panels will be invaluable to support more successful bidding in statistics.

Of our total external income (£2,468,637 on REF 4b), 90% was from UKRI, with the remainder from UK-based charities, including many smaller sums from the LMS, mainly to support small scale meetings, including ones run by our PDRAs and PGR students.

In the REF period, there were successful bids to the EPSRC as follows.

**Webb** (2014) £50k to fund an extended visit to the University of Queensland and Monash. The visit has led to several papers; [the third, recently accepted in \*Journal of Combinatorial Theory A\*](#), develops a powerful tool to extend finite partial Steiner triple systems, and applies this to construct uncountably many new countable homogeneous Steiner triple systems.

**Stallard** (2017) £391k mainly to appoint a three-year PDRA (this came third of the 25 bids considered at its panel). The work funded by this bid has led to results for several papers, one of which (c.50 pages, currently under review) gives the first ever classification of wandering domains in transcendental dynamics.

**Pradas** (2018) £203k for the project 'Droplets with dynamic size on smooth surfaces' to appoint a two-year PDRA. This has strengthened the ongoing collaboration with experimentalists at the University of Edinburgh and led to several papers, including one which establishes mechanisms to control droplets evaporating on solid surfaces, currently under review at *Physical Review Fluids*.

**Grimm** (2019) £349k for a project on spectral properties of aperiodic structures employing a three-year PDRA. This has already led to several significant results on the use of Fourier matrix cocycles to determine the presence of spectral components. As a result, **Grimm** was invited to write a [topical review for \*Acta Crystallographica A\* \(published September 2020\)](#) and to present a keynote lecture on "*State of the art understanding of diffraction from aperiodic crystals*" at the 25th IUCr congress in Prague (postponed to 2021), the triennial international meeting of the crystallography community.

In 2020, a further £677k of EPSRC funding was obtained, mainly in dynamical systems, 1) to extend the contracts of two PDRAs on existing projects affected by the Covid lockdown, 2) for **Yassawi's** New Investigator Award, and 3) for a New Horizons grant to **Grimm**.

The table below shows the UKRI bidding data related to gender in the REF period:

	Female	Male	%Female
<b>Successful</b>	2	2	50%
<b>Unsuccessful</b>	2	14	13%

Table 2: Bids to UKRI during 2014-20

Overall, the percentage of large bids (UKRI, ERC and Leverhulme) for external funding by women (27%) is similar to the percentage of women in the submission (26%), and their success rate has been higher. In general, the success rate is improving, with much greater mentoring of those applying for funding.

Finally, the School was the beneficiary of a substantial bequest (c. £50k) for research in the history of mathematics, which has been used to support a PDRA in that area 0.5 FTE for two years, leading to several outputs.

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

Members of the School make outstanding contributions to the research base in mathematics and statistics, well above what might be expected for a submission of this size, particularly in the areas of leadership, championing diversity, and public engagement.

##### External leadership roles and responsibilities

We make very substantial contributions in this area, both nationally and internationally, and particularly to the LMS and RSS. For example, **Barrow-Green** and **Stallard** have both had key roles on LMS *Council* and five members of the statistics group have played major roles with the RSS, including two vice-presidents, **McConway** and **Hilliam**. A selection of these leadership roles is given below.

##### **Barrow-Green:**

- \* elected member of LMS *Council* and LMS *Librarian* (2007–19) and member of LMS committees, including *Prizes Committee* and *Zeeman Medal Committee*
- \* member (currently Chair) of the Executive Committee of the *International Commission on the History of Mathematics* (2010–present)
- \* member of the *Italian Research Assessment Review Panel* (2016)
- \* member of the European Mathematical Society *Otto Neugebauer Prize Committee* (2018)
- \* Curator to the *International Mathematical Union* (2021)

**Farrington:** member of the RSS *Honours Committee* (2015)

**Garthwaite:** member and deputy chair of the RSS *Research Section Committee* (2014-17)

##### **Grimm:**

- \* chair of the *International Union of Crystallography's Commission on Aperiodic Crystals* (2014-15)
- \* member of the IoP *Mathematical and Theoretical Physics Group Committee* (2015)

##### **Hilliam:**

- \* member of the RSS *Professional Affairs Committee* (2019-20)
- \* elected member of the RSS *Council* (2020) and RSS *Vice-President, Professional Affairs* (2020-present)

##### **McConway:**

- \* RSS *Vice-president, Academic Affairs* (2014-15)
- \* chair of the RSS *Examinations Board* (2015-17)
- \* committee member of RSS *Data Ethics Special Interest Group* (2014-19)
- \* member of the *Council for the Mathematical Sciences* (2014-15)
- \* member of the NERC *Peer Review College* (2014-15)

**Širáň:** member of the *Slovak Committee for Awards in Science* (2014-18)

##### **Stallard:**

- \* chair of LMS *Women in Mathematics Committee* (2006–16)
- \* elected member of LMS *Council* (2014-19) and member of LMS committees, including *Research Grants Committee* and *Early Careers Committee*
- \* member of EPSRC *Postdoctoral Research Fellowships* panels (2016-20)
- \* member of the judging panel for the *L'Oreal-UNESCO UK and Ireland Women in Science Fellowships* (2015-19)
- \* member and Diversity Champion of the EPSRC *Mathematical Sciences SAT* (2020-present)

**Trendafilov**: elected member of the Board of Directors, *European Regional Section of the International Association for Statistical Computing* (2018 – 2022)

**Webb**: elected member and archivist of the *British Combinatorial Committee* (2001-17)

### Awards recognising research achievements

In 2016, **Stallard** received one of the inaugural *Suffrage Science Awards in Mathematics and Computing* awarded by the MRC; the scheme celebrates women in science 'for their scientific achievements and for their ability to inspire others'. Amongst the other seven awardees in 2016 were Professor Dame Celia Hoyles and Professor Dame Frances Kirwan.

In 2014, **Barrow-Green** received the *Chandler Davis Prize for Expository Excellence*, awarded by the *Mathematical Intelligencer* and funded by Springer, and was elected a member of the *Agder Academy of Sciences and Letters* (Norway). Also, in 2015, she was elected as a member of the *International Academy of the History of Science* based in Paris.

In 2016, **Gray** received the *Otto Neugebauer Prize*, awarded at the 7th ECM in Berlin, for highly original and influential work in the field of history of mathematics, and in 2018 he received the *LMS Hirst Prize* for his 'research and books on the history of mathematics, especially differential equations and geometry in and around the nineteenth century'.

### Research collaborations

School members are engaged in a wide range of fruitful research collaborations involving exchange visits and high profile publications.

These include externally funded collaborations such as: **Barbina** with Casanovas (Barcelona) by Santander, **Critchley** with Marriott (Waterloo), Oja (Tampere) and Li (Penn State) by EPSRC, **Grimm** with the Baake group in Bielefeld, by DFG, **Pradas** with Kalliadasis (Imperial), Galindo (Imperial) and Gavriilidis (UCL) by EPSRC, and with Ledesma-Aguilar and Wells (Edinburgh) by EPSRC, **Wilkinson** with Pumir (Lyon) and Huber (Chan-Zuckerberg Biohub, San Francisco) partly by KITP, **Rippon** and **Stallard** with Benini (Parma) and Fagella (Barcelona) and with Nicks (Nottingham) by EPSRC, **Trendafilov** with Valentini (Pescara), Gallo (Naples), Adachi (Osaka), Elden (Linköping) and Garcia (Salamanca) by Leverhulme, **Webb** with Bryant and Maenhaut (Queensland) and Horsley, Herke and Wanless (Monash) by EPSRC and the University of Queensland.

Other significant collaborations where exchange visits are involved include: **Jones** with Pewsey (Extremadura) and Kato (Tokyo), with Burke (Limerick), and with Marchand (Sherbrooke, Quebec), **Širáň** with Conder (Auckland), Jones (Southampton), Nedela (West Bohemia, Czech Rep.), Breda (Aveiro, Portugal) and Fiol (Catalan Polytechnic).

**Rippon** and **Stallard** are also part of the LMS Scheme 3 *Holomorphic dynamics* group, together with Imperial, Liverpool and Nottingham (2014-present).

### Research visitors

A steady stream of research visitors, over 40 in the period, spent time (at least a few days) in the School, including many of the collaborators listed above. Dedicated office space and computer facilities are provided for research visitors.

**Relation with research users to develop impact:** see the projects at the end of Section 1.

### Invited lectures

Many invited talks at international conferences and significant lectures, including:

**Barrow-Green**, *27th Nordic Congress of Mathematicians*, Stockholm (2016), *LSE Public Lecture* (2017), *Mathematics Symposium on the History of the Gender Gap in the Mathematical & Physical Sciences*, ICM Rio de Janeiro (2018); **Brignall**, *Permutation Patterns 2018*, Dartmouth College, USA (2018); **Grimm**, 23rd Congress of the International Union of Crystallography, Montréal (2014); **Pradas**, *XLVI Winter Meeting on Statistical Physics*, Taxco, Mexico (2017); **Širáň**, *International Conference on Combinatorics and Graphs*, Beijing (2014); **Stallard**, LMS Mary Cartwright Lecture (2016), LMS General Meeting (2017), Collingwood Lecture, Durham (2018), EMS meeting, Glasgow (2019), Edith Morley Distinguished Seminar, Reading (2019).

### Conference organisation

Organising and co-organising conferences is an area in which the School has contributed very significantly to the research base, with at least 30 external conferences co-organised in the period.

Highlights include: four ICMS workshops (**Critchley**, **Grimm**, **Mestel**, **Stallard**), a three week workshop at the *Mittag-Leffler Institute* (**Barrow-Green**), a symposium at the *25th International Congress of History of Science and Technology*, Rio de Janeiro (**Barrow-Green**), *SIGMAP14* (**Širáň**), *Permutation Patterns 2015* (**Brignall**), *ISCB 2016* (**Whitaker**), and an Oberwolfach mini-workshop (**Grimm**).

We also organised several annual one day conferences at the OU (Open Statistical Physics, Winter Combinatorics, Statistics), and **Rippon**, as chair of the *BMC Scientific Committee* (2017-20) arranged all future BMC locations up to 2024.

### Journal editing

Members of the School have been on editorial boards, associate editors or guest editors of over 30 journals in the period, including *Historia Mathematica*, *LMS journals*, *Journal of Combinatorial Theory Series B*, *Statistical Methods in Medical Research*, *Annals of the Institute of Statistical Mathematics*, *Statistics and Probability Letters*, *Computational Statistics*.

### Contributions to the economy and society

**Stallard**'s huge contribution to promoting the careers of women in mathematics, for example, as chair of the LMS *Women in Mathematics Committee* for 10 years, was recognised by being awarded an OBE for services to HE (2015). She also made a significant contribution to the LMS being awarded the inaugural *Royal Society Athena Prize* (2016), which celebrates individuals and organisations that have contributed most to the advancement of diversity in STEM.

**Hilliam** is Visiting Research Fellow in Medical Statistics at the University of Derby (2014-20), including training Doctor of Professional Practice students in statistics and research design.

**Whitaker** was a member of the *International Society for Pharmacoepidemiology*'s working group on *Guidance for the Application and Reporting of Self-Controlled Study Designs in*



*Pharmacoepidemiology* (2016-17). In January 2021, *Public Health England* declared that the Self-Controlled Case Study method will be a key tool in assessing the efficacy of the Covid-19 vaccines; see our SCCS impact case study.

**Farrington** has given expert advice to the *Tribunal de Grande Instance de Paris* in litigation over the teratogenicity of valproic acid (2018), and also expert witness to the *Paris Criminal Court* in litigation relating to the adverse effects of the drug Mediator (2019).

**McConway** gives statistics advice and training to a wide range of professional organisations: for example, journalists via the *National Press Foundation*, scientists via an NERC funded online course, NHS staff via the NIHR, and the *Association of British Science Writers*, and in 2020/21 he has made frequent expert comments on statistical information relating to the Covid-19 pandemic to most of the major media outlets, including eleven TV/radio channels.

### Outreach and public engagement

The School makes a massive contribution to mathematics and statistics outreach nationally, wherever possible drawing on our research expertise.

**Barrow-Green** (see our impact case study for more)

\* had a key role in the creation of the new *Winton Mathematics Gallery* at the Science Museum through her presence as a historian of mathematics on the advisory committee (2015-16)

\* was co-curator of *Sublime Symmetry*, Guildhall Art Gallery, London (2018)

\* was academic consultant for *Magic Numbers*, BBC4 (2018)

**Barrow-Green**, **Chicot** and **Stallard** have given numerous talks at events encouraging girls to study maths at university, for example at Oxford, Manchester, Lancaster and the OU.

**Chicot** was seconded as CEO of *MathsWorldUK* in 2018-19, during which she led a campaign to raise funds for the new museum, securing £160K for a national touring exhibition (partly based on **Grimm**'s research) and a pledge of £1.3 million for the museum from the Simon Norton Foundation; see <http://mathsworlduk.com/wp-content/uploads/2019/07/Newsletter-No5.pdf>.

**Chicot** was also member of the *Council of the UK Mathematics Trust* (2009-18) and of the *British Science Association, Mathematical Science Section* (2014-17), and co-created two OU open online resources *Returning to STEM*, aimed at people in STEM with long career breaks.

**RI Masterclasses**: The School has run several series during the period: at Bletchley Park (**Grimm**, **Pradas**) and in Bradford (**Chicot**), and has presented at the RI (**Adhikari**). Topics include mathematical tilings, awareness about misuse of statistics in the public sphere, and chaos theory.

**LMS 150th Anniversary Mathematics Festival at the Science Museum**: **Chicot**, **Grimm**, **Rippon** and **Stallard** were organisers and participants for two of the eight exhibits (aperiodic tilings and complex dynamics) (2015).

**Other maths outreach**: School members and PGR students have presented at very many of these, including: the *Big Bang Fair*, *Cheltenham Science Festival*, *Glasgow Science Festival*, *British Science Week* events in the *National Science and Media Museum* and the *National Children's Museum*, and most recently the *Northern Ireland Science Festival* (**Short** spoke about dessins d'enfant), *Maths Week Scotland* (**Pradas** spoke about chaos theory and **Short** about frieze patterns and tessellations).

**More or Less, BBC Radio4 (and World Service)**: the School has provided academic consultants for the programme throughout the current REF period (**McConway**, **Chicot**, and **Adhikari**). In 2020/21, the programme moved to a prime 9 am Wednesday slot and has had

huge influence during the Covid-19 pandemic, with total weekly audience figures of around 2.5 million. **Adhikari** has written follow-up articles on the statistics of Covid-19 on the OU's OpenLearn website.