

Environment template (REF5)

<p>Institution: University of Oxford</p>
<p>Unit of Assessment: 10 – Mathematical Sciences</p>
<p>a. Overview</p> <p>The University of Oxford has one of the largest and most diverse cohorts of mathematical scientists in the world, housed primarily within the Mathematical Institute (Oxford's Department of Mathematics) and the Department of Statistics. The two departments work closely at all levels, sharing an undergraduate degree, some appointments and numerous research activities. Since RAE2008, the University has made investment in the Mathematical Sciences a top priority.</p> <p>Investment in infrastructure: A new £72M building in central Oxford now houses all members of the Mathematical Institute; and the Department of Statistics has been allocated a new home, in which all its research groups will be co-located.</p> <p>Investment in people: We have appointed 54 new faculty (including six who came and left), 18 to newly-created posts, including:</p> <ul style="list-style-type: none"> • Six appointments spanning Number Theory and Discrete Mathematics, including Andrew Wiles and Ben Green; • Two new Chairs set up to support the Oxford Centre for Collaborative Applied Mathematics (OCCAM; Alain Goriely) and the Oxford Centre for Nonlinear PDE (OxPDE; Gui-Qiang Chen). <p>With 165 Faculty and Research Fellows, 53 Postdocs, and 256 graduate students, supported by outstanding facilities, we are able to pursue vigorously our strategy of maintaining research excellence across the whole spectrum of the Mathematical Sciences. To maintain the vitality of our research environment, we have established Hooke and Titchmarsh Fellowships (eight Fellows appointed), creating a substantial flow of early career researchers.</p> <p>Interdisciplinarity: We have seen a step-change in the scale of our interdisciplinary activity:</p> <ul style="list-style-type: none"> • We founded OCCAM with a \$25M grant from King Abdullah University of Science & Technology; • Over 54% of the faculty in our return wrote papers with coauthors outside mathematical sciences and 26% with coauthors outside academia; • We collaborated with over 143 companies; • Our faculty lead large interdisciplinary centres, e.g. Terry Lyons directs the Oxford-Man Institute (OMI) and Peter Donnelly directs the Wellcome Trust Centre for Human Genetics. <p>External indicators: The quality, quantity and diversity of our faculty and research have been recognised in many ways during the period, for example:</p> <ul style="list-style-type: none"> • Research income secured totalled more than £64M; • Three Presidents of the LMS and one of SIAM were chosen from our faculty; • Award of five Royal Society Medals and Prizes, three RSS Medals, two IMA Medals and 13 LMS Prizes; • Five of our faculty were elected Fellows of the Royal Society; • Nine of our faculty hold ERC Advanced Grants or Starting Grants; • In 2012, the main office of the Clay Mathematics Institute was moved from Cambridge, Massachusetts, to the Mathematical Institute, and Nick Woodhouse appointed as its President. <p>Research Groups: Research is loosely organised around a set of interleaving and highly interconnected research groups and centres: Algebra; the Centre for Mathematical Biology (CMB); Computational Statistics & Statistical Methodology; Discrete Mathematics; Functional Analysis; Geometry; History of Mathematics; Logic; Mathematical & Computational Finance; Mathematical Physics; Number Theory; Numerical Analysis; OCCAM; the Oxford Centre for Industrial & Applied Mathematics (OCIAM); OxPDE; Probability; Statistical Genetics, Bioinformatics & Protein Informatics; Stochastic Analysis; and Topology.</p>

b. Research strategy

Vision and context. We strive to be a world-leading centre for mathematical sciences, with a diverse research portfolio spanning the whole spectrum from fundamentals to applications. Our highest priorities are to foster excellence in research, to recruit and retain the best researchers, and to provide them with an environment in which they can thrive.

A key part of our strategy is to build and promote collaborations to maximise the impact of our research within the mathematical sciences, on other academic disciplines, and outside academia. This philosophy is embodied in the design of our new building, where careful planning of the layout provides the greatest possible opportunity for both planned and serendipitous interaction.

Our vision sits comfortably in the context of the University of Oxford's research strategy: to sustain existing excellence while promoting outstanding new initiatives within and across discipline boundaries. Strong institutional support provides crucial backing in the form of physical infrastructure, cross-disciplinary networks, and additional funding for posts.

Development and implementation of strategy. Both departments have committees whose remit explicitly includes monitoring the international research landscape and identifying emerging areas and new challenges as they arise. All research groups are represented and there is further input from our External Advisory Panels. The views of these committees underpin all appointments, ensuring that we take a holistic view of the research landscape and move in new directions where appropriate. For example, we built critical mass in Statistical Machine Learning using the resource released by the secondment of two Statistical Genetics faculty to the Wellcome Trust Centre.

Once identified and agreed, new initiatives are supported through appointments at senior and junior levels. To ensure critical mass, our policy is, wherever feasible, to support a senior appointment by providing further appointments in the same area and/or by allocating graduate studentships. For example, Goriely's appointment was supported by those of Vella and Moulton, and Chen's by that of Wang.

Alongside forward planning and targeted allocation of resources, we simultaneously maintain a high degree of flexibility, allowing us to respond quickly to the unforeseen developments that are intrinsic to research, to the new possibilities that arrive with new appointees, and to external opportunities of all kinds. OCCAM is a good example of this agility: within just six months of the award of the grant, the centre was active and new research themes were being launched.

(i) RAE2008 to REF2014

Our RAE2008 submissions identified both strategic scientific goals and institutional changes necessary to attain them. Before describing changes at the level of research groups, we illustrate the impact of our overarching strategy for the period.

Between 2001 and 2007, we saw a 44% growth in Mathematical Sciences faculty. A key strategic aim for 2008-13 was to foster research activity around the faculty appointed during the previous period. For instance, our initiative in discrete mathematics has developed into a full-blown research focus, with four new permanent appointments, including the recruitment of Green. A second strategic priority was to recruit world-leading individuals in key areas, around whom we could build thriving groups. For example, to support the recruitment of Wiles we created an additional senior faculty position (Kim) and two Senior Research Fellowships in Arithmetic Algebraic Geometry.

Part of our strategy is to help address national priorities for mathematical sciences, identified by the International Reviews. Thus, in 2007 with a £2.7M EPSRC Science and Innovation award, we set up OxPDE. Since 2008 we have invested heavily in the centre. Through international recruitment of four additional faculty and four Research Fellows, training of eight postdocs and 15 doctoral students, and co-organisation of activities nationwide, OxPDE has fulfilled its remit to address the deficit of UK-based researchers in PDE and provide a stimulus for national activity.

We entered the current period with a renewed focus on interdisciplinary activity, supported by the appointment of an interdisciplinary liaison officer. Such activity has grown dramatically, both at the level of individual researchers and through large centres including:

- OCCAM, established in October 2008, where 56 (from 78) research projects at doctoral and PDRA level have been undertaken in collaboration with scientists from other disciplines;
- the Wellcome Trust Centre for Human Genetics (Director, Donnelly; Director of Statistical Genetics, McVean), which has created a strong direct link between frontline research in human genetics and clinical medicine and our own in mathematical and statistical genetics;
- the OMI (Director, Lyons), an interdisciplinary centre which brings together mathematical, computer and social sciences in a programme of fundamental research in quantitative finance with a strong industry focus.

Our submissions to RAE2008 identified a need to restructure academic contracts to release more time for research and graduate training. This has been achieved. All new appointees and virtually all existing faculty benefit from these revised contracts. The size of the faculty has increased to accommodate this change of emphasis without reducing the scale and quality of undergraduate education. The result has been an increase in research activity, energy and excitement.

Developments in our Research Groups. We now turn to developments within individual research groups. We have gathered groups into 'themes' that reflect our strategic aims and emphasised the new directions for each theme. New researchers are listed in italics. Some faculty belong to more than one group and are listed in each. Research fellows (RFs) are listed in square brackets.

1. Algebra, Geometry, Topology and Mathematical Physics. *In RAE2008, we signalled our intention to increase our strength both in algebra at its interface with geometry and topology, and in geometry and topology with links to mathematical physics.*

Algebra: *Ardakov, Bridson, du Sautoy, Erdmann, Henke, Kremnizer, McGerty, Nikolov, Segal [Dyckerhoff, Kar]*

Geometry: *Berczi, Dancer, Hitchin, Joyce, Kirwan, Ritter, Szendroi*

Topology: *Bridson, Douglas, Drutu, Juhasz, Lackenby, Papasoglu, Tillmann [Ye, Casals-Ruiz]*

Mathematical Physics: *Alday, Candelas, De La Ossa, Ekert, Hodges, Mason, Sparks, Tod [Hollands, Lipstein, Lukowski, Monteiro, Suzuki]*

Research in **Algebra, Geometry and Topology** has been heavily influenced during the REF period by the rapid expansion worldwide of a more categorical approach. The new appointments of Ardakov, Kremnizer and McGerty in Algebra, Douglas and Juhasz in Topology, and Ritter in Geometry all bring to Oxford some aspect of this viewpoint and this has reinforced interactions between the groups. The increased activity bore fruit in the award of a £1.8M EPSRC Programme Grant in representation theory and geometry with Joyce as PI, as well as Douglas and Kremnizer's £1.6M EPSRC grant exploring an interface with computer science. The results of Joyce-Song are quoted (together with those of Kontsevich-Soibelman) in a host of papers in mathematics and physics concerned with "wall-crossing". Cross-fertilization of ideas on the Algebra/Topology interface has also been enhanced in geometric and profinite group theory with the appointments of Papasoglu and Nikolov, complementing the work of Bridson and Lackenby who both resolved long-standing conjectures in low-dimensional geometry. In **Mathematical Physics**, the appointment of Alday brings expertise in the AdS/CFT correspondence and a body of results and conjectures known as the AGT (Alday-Gaiotto-Tachikawa) conjecture which has stimulated much research in string theory as well as offering a large framework in which to view known results in representation theory. The importance of this work was recognized by the award of a €1.4M ERC grant. The expertise of Hodges is central to the explosion of international efforts uncovering remarkable geometric structures underpinning scattering amplitudes.

2. Number Theory, Logic and Discrete Mathematics. *A strategic aim highlighted in our submission to RAE2008 was to build our discrete mathematics group. The corresponding expansion in number theory is an example of the flexible, opportunistic, strand of our strategy.*

Number Theory: *Flynn, Green, Heath-Brown, Kim, Lauder, Sanders, Wiles [Balakrishnan, Johansson, Keil, Maynard]*

Logic: *Derakhshan, Koenigsmann, Pila, Zilber*

Discrete Mathematics: *Conlon, Green, Keevash, McDiarmid, Riordan, Sanders, Scott [Lenz]*

A milestone in the development of Oxford Mathematics was the appointment of Wiles, whose

inspirational presence launches our research in **Number Theory** in new directions. We have created a new faculty position in Arithmetic Algebraic Geometry (Kim) and another at the interface with Discrete Mathematics (Sanders). Aspects of the subject benefit from appointments in adjacent groups: Green to the Waynflete Chair, Pila to the Readership in **Logic**, and Ardakov in Algebra. Pila's outstanding series of results proving cases of the Andre-Oort conjecture shows the value of such intradisciplinary approaches. Since 2008, **Discrete Mathematics** has not only seen Green move from Cambridge to Oxford, but also the appointments of Sanders at the interface with Number Theory, Conlon with his groundbreaking results in Ramsey theory and graph regularity, and Keevash, whose arrival deepens our expertise in extremal and probabilistic combinatorics.

3. OCCAM, OCIAM, Numerical Analysis and CMB. *The integration of the Numerical Analysis group into the Mathematical Institute and the expansion of mathematical biology and medicine formed a key part of our future strategy in RAE2008, tied closely to an increased focus on interdisciplinarity. Our new activity in Energy dovetails into a university-wide strategic initiative. New appointments and the transformational presence of OCCAM have led to a step-change in activity.*

OCCAM: Breward, Byrne (joint with Computer Science), Erban, Goriely, Macdonald, Moulton, Vella, Wettlaufer [Griffiths, Lessinnes]. All faculty of OCIAM, Numerical Analysis and CMB are also affiliated with OCCAM.

OCIAM: Breward, Chapman, Dellar, Fowler, Goriely, Grindrod, Hewitt, Howell, Howison, Moroz, Münch, Oliver, Please, Porter, Vella, Waters, Wettlaufer [Hall, Trinh]

Numerical Analysis: Cartis, Giles, Gillow, Hauser, Kay (joint with Computer Science), Macdonald, Sobey, Süli, Tanner, Trefethen, Wathen [Farrell, Hewett]

CMB: Baker, Byrne, Erban, Gaffney, Maini, Moulton, Whiteley (joint with Computer Science) [Bruna, Gadelha, Harrington, Vejchodsky, Yates]

OCCAM was established in 2008 with \$25M from King Abdullah University of Science and Technology (KAUST) – the largest single mathematics grant ever awarded to a UK university. The Centre brings together, but does not subsume, **OCIAM**, **CMB**, the **Numerical Analysis Group** and the Computational Biology Group (Department of Computer Science). Research across these groups in biological and medical themes has seen initiatives in cancer modelling, led by Byrne, and in growth and morphology, catalysed by the arrival of Goriely and Moulton. Erban has built up a large group in stochastic methods for biological processes, assisted by a €625K ERC starting grant. Work in tissue engineering has expanded to include three faculty members. New faculty appointments have greatly strengthened work in industrial mathematics (Breward, Grindrod, Please) and in fluid mechanics (Münch, Vella). A strategic initiative in geoscience led to the appointments of Hewitt and Wettlaufer. Energy forms a new strand of our research, with activity in smart grids, photovoltaics and batteries involving 7 faculty members. The Numerical Analysis group relocated from Computer Science to Mathematics during the period and many new research links with OCCAM, OCIAM, OxpDE and others have followed. There has been a notable expansion of activity in optimisation and compressed sensing, with the arrival of Tanner and Cartis, while Macdonald has brought expertise in surface computing. Chebfun has matured over the period from the prototype version 1 to version 4, a large open source software project that has hundreds of programs, tens of thousands of lines of code, and thousands of users.

4. OxpDE. *Our substantial investment in the centre, which was still in its infancy in RAE2008, addresses a national strategic priority.*

Members are: Ball, Capdeboscq, Chen, Kristensen, Nguyen, Seregin, Shkoller, Süli, Wang [Caravenna, Xiang, Yung]

Founded in 2007, **OxpDE** has stimulated UK research in PDE in many ways, for example through joint activities with the Maxwell Institute in Edinburgh, and initiatives such as the annual South-West PDE Winter School. The appointment of Chen in 2009, to a newly established Chair, has brought research leadership in quasilinear hyperbolic and mixed-type systems to the UK, while research in general relativity and geometric PDE has been reinforced by Nguyen and Wang, and in the PDE of fluid mechanics by Shkoller. Ball has built a large research team working on microstructure in solid and liquid crystals with support from a €2M ERC grant.

5. Stochastic Analysis, Probability, and Mathematical & Computational Finance. *In RAE2008 we identified stochastic analysis and its links to applied groups, and mathematical and computational finance as areas for strategic growth. New appointments in both departments and the development of the OMI have been essential in achieving these goals.*

Stochastic Analysis: *Beliaev, Deligiannidis, Etheridge, Hambly, Lyons, Qian, Tarres*

Probability: *Deligiannidis, Etheridge, Goldschmidt, Hammond, Martin, Reinert, Steinsaltz, Stirzaker, Tarres, Winkel*

Mathematical & Computational Finance: *Cohen, Deynne, Farmer, Giles, Gyurko, Hambly, Hauser, Howison, Jin, Monoyios, Obloj, Reisinger, Zhou [Hu, Klimmek, Ruf]*

A major focus in **Stochastic Analysis** in the period has been Lyons' theory of rough paths and its rapidly expanding range of applications from the interpretation of financial data to the numerical analysis of nonlinear PDEs. An important new direction, stimulated by the appointment of Beliaev, is Stochastic Loewner Evolution. Research in **Probability** both complements and overlaps with that in the stochastic analysis and discrete mathematics groups. The group is strongly motivated by applications especially in population genetics, network modelling and demography. The appointments of Deligiannidis, Goldschmidt and Hammond greatly strengthen the connections between Mathematics and Statistics. Hammond's work on rigorous analysis of models from statistical mechanics also brings new links with Theoretical Physics. Goldschmidt brings expertise in scaling limits of large random structures, exemplified by her proof of the scaling limit of the Erdős-Renyi random graph at its critical point. The **Mathematical & Computational Finance** Group (MCFG) has seen rapid and significant expansion since 2008 in tandem with the OMI, which has grown from a small nucleus at its inception in 2007 to become a world-leading interdisciplinary academic institute for research in quantitative finance, providing £15.5M of which 35% was spent on mathematical sciences research. All the MCFG are members of the OMI. Funding from Man Group also established a new Chair in Quantitative Finance, to which Thalea Zariphopoulou was appointed as our first female Statutory Professor. New directions include Robust Market Models (Obloj) and applications of BSDEs (Cohen).

6. Statistical Genetics, Bioinformatics & Protein Informatics and Computational Statistics & Statistical Methodology. *In RAE2008 we stressed the importance of maintaining and enhancing Oxford's world-leading position in statistical genetics. This was achieved in a way that released resources that were used to build critical mass in statistical machine learning.*

Statistical Genetics, Bioinformatics & Protein Informatics: *Deane, Hein, Holmes, Massa, McVean, Marchini, Myers (Donnelly and McVean are returned under UoA5)*

Computational Statistics & Statistical Methodology: *Burke, Doucet, Evans, Holmes, Lauritzen, Massa, Matechou, Nicholls, Reinert, Ripley, Snijders, Steinsaltz, Teh. [Caron]*

Research in **Statistical Genetics, Bioinformatics & Protein Informatics** has thrived. Statistical Genetics has particularly benefited from strengthened links with the Medical Sciences Division, galvanised by the secondments of Donnelly and McVean to the Wellcome Trust Centre for Human Genetics, and our central role in the 1000 Genomes Project. In a new direction, a group led by Reinert and Deane are developing the area of protein interaction graphs, fusing research in network probability and computational biology. The **Computational Statistics and Statistical Methodology** group has expanded significantly, with Burke, Massa and Matechou bringing further expertise in applied statistics, Evans reinforcing our strength in graphical models, and the key appointments of Doucet and Teh in Statistical Machine Learning and Monte Carlo Methods. We now have substantial activity developing Monte Carlo methods for Bayesian inference for complex non-parametric models in a wide range of scientific settings. A particular focus is Doucet's groundbreaking approach based on particle Markov chain Monte Carlo. The group has prioritised the building of strong links across the UK statistics community, for example, through the first EPSRC Programme Grant in Statistics (Warwick, Bristol, Lancaster, Oxford, £2.4M).

Our small research groups in **Functional Analysis** (Batty, Haydon) and **History of Mathematics** (Stedall) have not had any new appointments during the period, but they continue to thrive.

(ii) Current strategic aims

Our highest priorities are unchanged: to foster absolute excellence in research, to recruit and retain the best researchers and to provide them with an environment in which they can thrive. We regard it as crucially important that we maintain our investment in fundamental research of enduring significance. Equally, we are committed to promoting the synthesis of ideas from different areas of mathematical sciences and to driving forward interdisciplinary initiatives.

We expect that developments in the upcoming period will be centred around the eight Chairs we anticipate falling vacant. Four of these Chairs are in the Department of Statistics: to take full advantage of this important opportunity, the Department's Research Strategy Committee is considering all these posts together, ensuring that we maintain the breadth of our activities. A further four Chairs are anticipated in the Mathematical Institute, three in specific areas (described below) and one, the Sedleian Professorship, in applied mathematics more broadly. Our key objective is to attract world-class research leaders who we will support through faculty appointments and targeted use of our Hooke and Titchmarsh Fellowships.

Many of our scientific priorities span our research themes, and indeed form an essential part of wider university strategy, reflecting our continued commitment to interdisciplinary research. For example, we shall expand our work on energy, a strand in which we have 10 faculty across the UoA working on problems from energy storage to nuclear fusion, and on water resources. The renewal of our CDT in Systems Approaches to Biomedical Science will promote research and training at the interface with life sciences and the pharmaceutical industry. Faculty from across the UoA are driving forward university-wide activities in big data and we anticipate significant growth in this area, supported in part by our new CDT in Next Generation Statistical Science (joint with Warwick). The University's investment in other disciplines also brings exciting new opportunities. For example, we are exploring new research avenues at the interface with Computer Science.

The plans for our research themes are as follows.

(1) Algebra, Geometry, Topology and Mathematical Physics: New appointments in both Mathematical Sciences and Physics are expected to result in new collaborations right along the interface between the two disciplines, from string theory to discrete random structures. Anticipated professorial vacancies in Geometry and Mathematical Physics, while still some years away, provide the focus for strategic planning. The replacement of Rouquier with Green has created a lacuna in Algebra which will be reviewed in 2014.

(2) Number theory, Logic and Discrete Mathematics: We expect consolidation following recent rapid expansion. We will support our new appointees as they develop their presence here. The upcoming professorial vacancy in mathematical logic provides the opportunity for new directions.

(3) OCCAM, OCIAM, Numerical Analysis and CMB: Our recently expanded faculty team in optimisation will be supported and encouraged to build up a cadre of PDRAs. Our key aims are to broaden our long-established research engagement with industry, with our new CDT in Industrially Focused Mathematical Modelling playing a pivotal role, and to work to build and maintain long-term partnerships with large corporations. As part of our strategy of engagement with other sciences, we will further expand our activity in mathematics applied to biology, medicine, and geoscience.

(4) OxpDE: Our priority is to exploit the fresh perspectives brought by our new appointments and thereby broaden the centre's role in providing national leadership, facilitated through support for visitors and workshops. A key focus will be training the next generation of analysts through our new CDT in Partial Differential Equations: Analysis and Applications.

(5) Stochastic Analysis, Probability, and Mathematical & Computational Finance: We will pursue opportunities for the use of sophisticated mathematical techniques on novel applications, e.g. developing new directions in the mathematics of machine learning via the theory of rough paths, while driving forward interdisciplinary initiatives ranging from big data to complex systems.

(6) Statistical Genetics, Bioinformatics & Protein Informatics, and Computational Statistics & Statistical Methodology: We will grow our core research in computational statistics, scalable methods and statistical machine learning, and cement our activities with the Wellcome Trust

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Centre for Human Genetics, for example through joint appointment of faculty and/or research group leaders in Applied Statistical Genomics.

Intellectual environment. As a world-leading centre for research in the mathematical sciences, we must be at the forefront of developments in the subject and ready to respond nimbly to research challenges as and when they arise. This requires sustained international engagement and a continual flow through Oxford of the highest quality researchers. Therefore we will:

- Build further international alliances, to engage with people at all levels from the best institutions around the world;
- Establish a Visiting Professorship programme to support long-term visitors, exploiting the doubling of visitor space in our new accommodation;
- Continue to enhance our graduate training, exploiting the diversity of our faculty and our four new Centres for Doctoral Training to provide a thorough and coherent training in the core of the discipline, and building on the success of our work with industry;
- Raise money for graduate scholarships, moving towards a situation in which we can attract and fund the best research students, irrespective of nationality;
- Recognising the transformative nature of the large grants that enabled us to set up OxPDE and OCCAM, we will seek out, and respond to, similar opportunities.

Exploiting our investment in infrastructure. With the new Mathematical Institute building complete and a new home for Statistics identified, there is a tangible feeling of excitement around mathematical sciences in Oxford. We wish to capitalise on this huge investment in infrastructure, not only by providing our own researchers with the most stimulating research environment we possibly can, but also by raising the profile of UK mathematics. With this in mind, we will:

- Exploit the new and significant opportunities provided by the move to Oxford of the Clay Mathematics Institute, for example, through hosting research workshops, summer schools and the annual Clay Research Conference and extended visits by speakers at these events;
- Host large research meetings, with Stochastic Processes and their Applications 2015 and the BAMC 2016 already booked;
- Establish a Distinguished Lecturer series in statistics to complement our mathematics colloquia and Visiting Professorships;
- Work to extend our outreach and public engagement programme through the activities of our recently established Office of External Relations, which complements the activities of the Charles Simonyi Professor for the Public Understanding of Science (Marcus du Sautoy).

c. People, including:**i. Staffing strategy and staff development**

Staffing strategy in relation to research strategy and physical infrastructure. Our overarching aim is to ensure the recruitment, retention and motivation of academics who will contribute at the highest level. In keeping with our research strategy, appointments are often targeted at specific areas (identified by our research committees). This may be to strengthen existing themes, or to build new capability. For instance, we prioritised the new area of mathematical geoscience, resulting in the appointments of Hewitt and Wettlaufer. We also make opportunistic appointments when this is appropriate, for example with Wiles' Professorship, or by creating positions for holders of Royal Society University Research Fellowships (e.g. for Erban, McGerty, Juhasz and Sanders). Another mechanism is the establishment of personal research chairs to enable recruitment and retention of top people. Five faculty (Bressloff, Etheridge, J Ockendon, Tillmann, Wettlaufer) were appointed to such posts, adding to the three previous postholders (Giles, Joyce, Kramkov).

Mathematical Sciences have expanded greatly during the period and the University facilitated this by renting and renovating additional space. During the planning and construction of the new mathematics building, we extended OxPDE's temporary accommodation to house OCCAM and the Numerical Analysis group. By relocating Mathematical Physics, Discrete Mathematics and Stochastic Analysis, space was released to enable expansion in other areas without breaking up research themes. Co-location of Statistical Genetics, Protein Informatics and Bioinformatics with groups from biosciences greatly enriched, and led to huge growth in, interdisciplinary activities.

Uniting research groups in our new departmental homes, while maintaining a presence in large interdisciplinary centres, is key to our strategy of promoting interactions across the whole spectrum of our activities. Our physical environment is now a significant factor in attracting researchers at all stages of their careers to come and work in Oxford.

Career development support. Academic staff receive targeted support according to their needs and the stage of their career.

New Academic staff. All new faculty have a mentor, who offers them confidential guidance and support for all aspects of their academic life as they establish their research and teaching portfolio. Academic staff are appointed initially for a five-year probationary period, during which they are particularly encouraged to attend appropriate university seminars and training courses on aspects of university duties such as the supervision of doctoral students. A formal review after two years provides the opportunity for critical reflection and identifies actions and support needed for successful completion of probation. Newly appointed faculty begin their career with a reduced teaching load and, if this is their first faculty post, they will also be shielded from administrative and examining duties for the first five years, giving them time to consolidate their independent research programme. A comprehensive induction involving senior members of the UoA covers teaching, research, and support in planning for research funding. Early career faculty are especially encouraged to write grant applications and they receive significant assistance from the Research Facilitation team (see section d) and/or an existing grant holder in the same research area in planning the project, writing the proposal, and responding to referees. The University's John Fell Fund is a valuable internal source of funding, particularly appropriate for early career researchers, which provides seedcorn funding of up to £100k for new initiatives and projects. Four of our early career faculty have received awards, each providing funds for a 12 month postdoctoral researcher.

Established Academic staff. An annual appraisal scheme provides an opportunity for staff to assess their own performance and career development. Crucially it is also a systematic means by which Heads of Department can assess workloads and ensure that adequate time is available for research. The University recognises the significant challenges of maintaining a high level of research activity throughout an entire career and provides mechanisms through which faculty can renew and refresh their research. The most important of these is the sabbatical scheme through which all staff are entitled to one term of sabbatical leave for every six terms worked. Staff are fully funded during sabbaticals and everyone is encouraged to apply. In the period, 54 faculty members have collectively benefited from 107 terms of leave. Trade-off and buy-out schemes temporarily relieve lecturers from some of their teaching duties in order to focus on research and start-up schemes and dowry funds assist new lecturers and professors. All faculty are encouraged to apply for research fellowships and are supported throughout the process, from application to interview.

All faculty have access to Departmental and College research support funds, averaging around £1,900 per annum. Incentive schemes reward grant holders with small pots of money that can be spent on anything that supports research in their group. Faculty can also draw on departmentally allocated funds to support visits and visitors. Members of some groups have access to significant research support funds from external sources, for example those in OCCAM, OxpDE or the Oxford-Man Institute. Our EPSRC Platform Grant in Mathematics provides support for feasibility studies, visitors, extended visits abroad for the purpose of initiating grants, and workshops.

Research fellows (RFs) and Post-doctoral Research Assistants (PDRAs). There have been 70 RFs and 166 PDRAs over the period. This has guaranteed a thriving community, central to the vitality of the UoA. They are integrated into all aspects of our research activity. Each is assigned a faculty mentor who is available to offer support and advice on developing their career. They are encouraged to deliver lecture courses and classes (for which there is training) and they often lead reading groups and junior seminars, where RFs, PDRAs, and students can present work and discuss ideas in a relatively informal setting. Research Fellows are expected to run their own research programmes and generate activity. PDRAs are encouraged to undertake independent research alongside their directed research. Our RFs and PDRAs have a strong record of achievement. For example, Olver won the Adams prize for work completed in Oxford, Davit was in the top five in the national competition for CNRS posts, Nadtochiy left for a tenure-track position at University of Michigan at Ann Arbor, and Cass and Yau moved to lecturerships at Imperial College.

Implementation of the Concordat on Career Development of Researchers. The University enthusiastically endorsed the principles of the Concordat and produced two codes of practice, on Staff Recruitment and Selection, and on Employment and Career Development of Research Staff, which map the Concordat onto the University's organisational structure. All departments are obliged to embed these codes into their operations. In addition to the basic requirements, each of our researchers benefits from three formal meetings: (i) to establish expectations and aspirations, (ii) to review the first year's progress and suggest avenues for career development, and (iii) to discuss the likelihood of further funding and/or options for the future. Support for implementation is provided by the Oxford Learning Institute (focusing on personal and professional development issues), Personnel Services (HR issues), Research Services (research grants, ethical issues and research integrity), the Equality & Diversity Unit, and the Careers Service. We encourage our research staff to take advantage of personal and career development courses ranging from Teaching Skills and Career Management to Business Building and Entrepreneurship. The Oxford Language Centre offers courses in Academic Writing, Advanced Communication Skills, English courses for staff whose first language is not English, and foreign language courses. Our Teaching Advisor provides support specific to undergraduate teaching across the mathematical sciences.

Evidence of the success of the University in supporting and developing research staff is the award of the European Commission's HR Excellence in Research Award, which recognises the systems and practices in place to ensure successful implementation of the Concordat.

Personal fellowships. We have hosted 124 personal research fellowships during the period. External funds supported 98 of these while the rest were supported by the University and Colleges.

A large part of the external funding comes through direct applications by individuals to competitions run by external bodies. This accounts for 55 fellowships awarded (or held) during the period: two EPSRC Senior Fellows (*Bridson, Kirwan*), one EPSRC Senior Media Fellow (*du Sautoy*), four EPSRC Advanced Fellows (*Dellar, Lackenby, Martin, Waters*), three new-style EPSRC Fellows (*Ardakov, Doucet, Farrell*), two EPSRC Career Acceleration Fellows (*Hammond, Majumdar*), eleven EPSRC Postdoctoral Research Fellows (*Bui, Davies, Dudas, Goldschmidt, Harrington, Hasson, Kar, Kirby, Schramchenko, Sprittles, Turner*), one Royal Society 2010 Anniversary Professor (*Wiles*), nine Royal Society University Research Fellows (*Conlon, Erban, Hausel, Juhasz, Lauder, McGerty, Roose, Sanders, Sparks*), one Royal Society Dorothy Hodgkin Fellow (*Hollands*), 14 Marie-Curie Fellows (*Addario-Berry, Ben-Bassat, Caron, Casals-Ruiz, Danz, Kariagiannis, Lessinnes, Miemitz, Monteiro, Pacini, Pierce, Suzuki, Tanaka, Vejchodsky*), two MRC Special Training Fellows in Biomedical Informatics (*Rantalainen, Yau*), one Leverhulme Trust Senior Research Fellow (*Szendroi*), two Leverhulme Trust Research Fellows (*Mason, Vella*), and two Leverhulme Trust Emeritus Fellows (*J Ockendon, Penrose*).

Independent Research Fellowships are a built-in component of some research grants and donations. These Fellowships are awarded in open competitions administered by Oxford. Three Fellows were funded by the Simons Foundation (*Lipstein, Torres, Ye*), six by our Nomura grant (*Danilova, Dean, Gupta, Klimmek, Szpruch, Xu*), seven by our KAUST grant (*Erban, Farmer, Griffiths, Majumdar, Peppin, Reis, Sprittles*), five by Man Group through OMI (*Henderson, Hu, Liang, Nadtochiy, Ruf*), three through the OXPDE grant (*Caravenna, Xiang, Zarnescu*), and two by EPSRC for Number Theory (*Johansson, Keil*).

A substantial flow of new researchers is fundamentally important to the vitality and sustainability of our discipline and so, partly in response to a changing external environment, we have extended and broadened OXPDE's Titchmarsh Fellow and OCCAM's Research Fellow models to establish Departmental Titchmarsh and Hooke Research Fellowships. There are currently eight of these in post (*Balakrishnan, Dyckerhoff, Gadelha, Hall, Harrington, Hewett, Lukowski, Yung*). Departmental fellowships complement a particularly valuable resource in Oxford, namely college-supported Junior Research Fellowships (JRFs). These are generally fully funded three-year positions, often open to a range of disciplines. Competition is intense (eg 40 mathematics applicants per place). *Bate, Bruna, Cohen, Craven, Dudas, Giansiracusa, Gile, Lamberti, Lenz, Lotay, Maynard, Olver, Savov, Shipley, Stewart, Thomas, White* and *Yates* held fully-funded JRFs in the period.

We provide the same level of support whether or not Fellows are on our payroll. In the latter

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category we hosted two Royal Commission for the Exhibition of 1851 Fellows (*Kazachkov, Majumdar*), two NSF Postdoctoral Fellows (*Cavendish, Pierce*), one Simons Foundation Fellow (*Schwartz*), one AGAUR Fellow (*Casals-Ruiz*), one DAAD Fellow (*Spruessel*), one Feodor Lynen Research Fellow (*Breit*), one Forderung der Wissenschaftlichen Forschung Erwin Schrödinger Fellow (*Takacs*), one Fondation Philippe Wiener Fellowship (*Lessinnes*), one FQRNT postdoctoral fellowship (*Harutyunyan*), one IRCSET Postdoctoral Fellow (*Melnik*), one NWO Rubicon Fellow (*Veerman*), one Schlumberger Foundation Fellow (*Shaheen*), one Swedish Research Council Fellowship (*Lafors*), one LMS Grace Chisholm Fellow (*Cominetti*) and one KC Wong Fellow (*Gu*).

Three of our faculty (*Ball, Lyons, Trefethen*) have received ERC Advanced Investigator Grants in the period, while six faculty members (*Alday, Erban, Green, Keevash, Lauder, Obloj*) received ERC Starting Grants. Finally, ten faculty (*Alday, Ball, Bressloff, Bridson, Chen, Goriely, Rouquier, Shkoller, Wettlaufer, Zhou*) received Royal Society Wolfson Merit Awards.

International staff appointments and recruitment, and visiting scholars. Of our 54 new faculty appointments, 23 came directly from overseas institutions, including Berkeley, Princeton and Yale. Of the 21 permanent faculty that have left, 12 have retired and the remainder moved elsewhere, for instance to senior posts at Bonn, EPFL Lausanne, and UCLA. Of the 191 RFs and PDRAs who joined us during the period, 91 were recruited from overseas.

Visitors play a key role in maintaining our intellectual vibrancy. Over the period we have hosted over 1010 visiting scholars, at all levels, for visits of anything from one day to two years. These are often funded by external grants or research incentive funds held by individual researchers, but in addition, OCCAM, OxPDE, the Oxford-Man Institute and the EPSRC Platform Grant all provide support for the visitor programme (OCCAM, for example, has spent £1.42M on bringing visitors to Oxford), as do our seminar and colloquium funds, which support over 750 research seminars per year. Over 130 workshops have brought around 5000 external attendees to Oxford. Mathematical scientists can apply for various distinguished lectureships and professorships supported by the University; for example, Steve Evans was an Astor Lecturer in 2009. Some Oxford colleges support Visiting Research Fellowships, appointed in open competition, and these have brought high profile visitors such as Martin Barlow, Michael Harris and Richard Schwarz.

Support for equality and diversity. The University of Oxford is committed to fostering an inclusive culture, which promotes equality and values diversity. With the help of a dedicated central unit, we work to ensure that our pursuit of excellence goes hand in hand with equality of opportunity. Our faculty in mathematical sciences are drawn from 30 different countries, with 51% from outside the UK. We are proud to have eight women Professors (of whom two are FRS), but the under-representation of women in mathematical sciences remains of particular concern to us. We have Good Practice Steering Groups, which meet once a term and whose membership ensures representation of all constituencies in the departments. These groups have driven preparation of Athena SWAN applications (Mathematical Institute awarded Bronze in 2013) and developed and promoted a range of initiatives that supplement our mentoring schemes, including:

- Positive action to ensure a family-friendly working environment, including the moving of seminars and departmental committee meetings to be in core working hours to enable those on the school run to attend. Our staff contracts give considerable flexibility to faculty, in terms of the ability to organise the timing and content of teaching and research;
- Weekly “Mathematrix” lunches which provide a forum for discussion of issues typically of concern to female mathematical scientists, but relevant to all;
- The Oxford Women’s Network (OWN), a university-run service that provides women working at all levels in the University with support services, giving practical advice and guidance on all aspects of their career;
- The University-wide Springboard and Navigator programmes, which support the career development of women and men respectively;
- The University-wide Ad Feminam mentoring scheme, which encourages mid-career women to develop their leadership potential with the aim of increasing the number of women in senior university roles;
- The University’s childcare services, in particular the nursery and holiday play schemes.

The University's Equality and Diversity unit has developed University-wide policies that ensure that there are both men and women on all appointment panels and committees, that all recruitment and promotion exercises are monitored, and that parental leave is supported and encouraged. Other activities of the unit include coordinating a network of departmental harassment advisors and providing advice to departments on support for disabled staff, students and minorities.

The Mathematical Institute involved a wide range of staff and students in user groups for the final stages of the design of its new building, to ensure that it meets the needs of all staff and students and provides facilities such as a first aid/pregnant and breastfeeding staff room. Similar detailed planning is now underway for Statistics' new home.

The departments greatly value the contribution of retired faculty, who are often still actively engaged in research, teaching and graduate supervision. Where appropriate, they have office space and facilities, and receive a small research allowance.

ii. Research students

High-quality training of research students is essential to the long-term health of mathematical sciences in the UK. We attract extremely strong students and having the resources to provide them with training at a level comparable with the highest international standards. There are currently 78 home, 80 EU and 98 non-EU research students in the Mathematical Sciences. Additional graduate training is provided through our five MSc courses: Mathematics and the Foundations of Computer Science (19 students, in 2012/13), Mathematical Modelling and Scientific Computing (22 students), Mathematical and Computational Finance (28 Students), Applied Statistics (34 students) and Mathematical Finance (part time, 73 students).

PGR recruitment. Our annual Mathematical Sciences Graduate Open Day offers potential applicants a range of formal presentations and the opportunity to meet current students and faculty while browsing research-group stalls. Specific studentship projects are advertised via email to colleagues in other universities and on jobs.ac.uk. Our extensive international network of collaborators is a valuable source of candidates and we are also fortunate to attract excellent direct applications. Our MSc courses are key recruiting grounds for PGRs (15% of those admitted); 14% of our PGRs come to us through Oxford's Doctoral Training Centres. All DPhil students we have admitted have a first class undergraduate degree, an MSc, or overseas equivalent. To encourage students to consider research, we promote and fund Undergraduate Summer Studentships (87 during the period). Since 2010, we have also run the annual six-week residential "Oxford Summer School in Computational Biology" for undergraduates (35 students in 2012).

We consider applicants in gathered fields based on a written application and an in-person or Skype interview for those shortlisted. Places and funding are offered strictly on merit. Competition for places is strong: for 2012/13 start we had 337 applications and took 58 new research students in the two Departments (not including DTC students). We have used our EPSRC Doctoral Training Grant to support 115 new students. A small number of these awards were targeted to specific research projects. There are three University-funded Clarendon studentships per year in Mathematical Sciences, providing full funding to non-UK students, and there have been five Rhodes Scholars in the period. Support is also available via Teaching Assistant Bursaries and college scholarships.

Training and support mechanisms. Our long-standing tradition of broad education has enabled us to adapt easily to EPSRC's requirement of 100 hours of broadening training. We have adopted this for all students, irrespective of their source of funding. Graduate students choose from over 95 courses at M-level or above from within the UoA and 23 courses laid on by two EPSRC-funded PhD Taught Course Centres (the Oxford, Warwick, Imperial College London, Bath and Bristol Centre, and the Academy for PhD Training in Statistics). Oxford's Graduate School offers around 350 courses in other science departments. Courses are assessed and form part of the transfer of status at the end of the first year (see below). Students also take courses on specific topics relevant to their own theses and are encouraged to attend residential training events such as international summer schools, LMS-EPSRC short courses, and the Graduate Modelling Camp (run in Oxford each Easter since 2010). Our extensive seminar programme provides a key component of all graduate students' research training; students are expected to attend.

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We have benefited from involvement in three EPSRC DTCs in the period: the Life Sciences Interface DTC, the Systems Biology DTC, and the Systems Approaches to Biomedical Sciences Industrial Doctoral Centre (SABS-IDC). Over 40 students enter these courses each year; 49 have gone on to complete their DPhil within one of our departments. The SABS-IDC is directed from within the Statistics department. This centre pioneered open innovation industrial doctoral training and has 14 partners from the pharmaceutical industry, all of whom contribute to both the teaching and research projects of the students. Our four new CDTs provide an exciting opportunity to develop cohort-based training across the UoA.

To develop communication skills and the ability to speak to broad audiences, graduate students from each research area organise informal weekly meetings where they describe their work to their peers, or solicit talks on specific topics. Graduate students in Applied Mathematics have launched a SIAM Student Chapter, now the largest such Chapter outside the US, which attracts sponsorship from Winton Capital, BNP-Paribas, BP and the Mathematical Institute. The Chapter lays on networking events for its members, along with an annual one-day conference. There are weekly research overview talks by faculty aimed at graduate students. Instruction on giving talks and classes is provided through both University-run and department-run courses. A training programme in transferable and research skills is available to all graduates and there are courses on programming in C++ and Matlab, scientific computing for doctoral students, and a "Problem-Solving Squad". There are courses in LaTeX and IT skills, "Research Integrity" and "Academic English", along with courses on career development, enterprise and entrepreneurship and personal effectiveness.

All graduate students have as a minimum an academic (primary) supervisor and an advisor (mentor), who oversee their research development. Every graduate student belongs to a college and has a college advisor. Joint supervision is a regular practice and students working in interdisciplinary areas often have a co-supervisor in another department. Generous funds are available for graduate students to attend conferences, workshops, summer schools and other events: students can draw upon ring-fenced sums (around £1,200 per student, with additional funds for training elements), and this sum is usually more than matched by the student's college.

Progress monitoring. The research programme of every graduate student sits within a framework of continuous close monitoring punctuated by two formal assessments. Research students arrive in Oxford as Probationer Research Students. By the end of the first year, they must have prepared and delivered a presentation (either to those responsible for assessing the student's work, or a larger audience) and have submitted a dissertation detailing research progress during the first year and plans for the future; this is examined orally by two members of faculty. There is a further oral examination in the third year, to ensure the student is on track to complete the thesis, and to offer advice and support. Each College has a Tutor for Graduates and provides tailored pastoral, financial, welfare and academic-related support. Termly supervisors' reports and student self evaluations supply information to the department, university and college.

Both Departments have committees responsible for policy on research student education, training and admissions. Other graduate student matters, including admission of students, appointment of examiners and approval of their reports are the responsibility of the departments' Directors of Graduate Studies, who have dedicated administrative support.

Excellence in research training is highlighted by the achievements of our students who have graduated since 2008. For example, Kimpton won the 2013 Lighthill-Thwaites Prize, Gadelha, Rindler, and Warnke were elected to JRFs in Cambridge, Nicolau took up a Miller Postdoctoral Fellowship at Berkeley, and He went to a tenure-track position at Columbia.

d. Income, infrastructure and facilities

Specialist infrastructure and facilities. Oxford has unparalleled library holdings, with access to more electronic journals than any other UK institution (>30,000 titles). The Bodleian Library (one of the three copyright libraries in the UK with a stock of over one million science titles) and the departmental libraries house large selections of books. There are extensive bench collections in OCIAM, OCCAM, CMB and Numerical Analysis and college libraries buy books on the recommendation of faculty and students. All library holdings are accessible via a single catalogue. The Mathematical Institute has set up a small "wet lab", funded by the KAUST grant, where

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tabletop experiments are undertaken. Studies that have been undertaken include: the drying and freezing of colloids, formation of Tyndall stars, self-assembly of magnetic spheres, the wrinkling of beach balls, snap-through instabilities, self-organisation in shaken rods, and most recently, the collective behaviour of interacting robots.

Our extensive IT networks provide a comprehensive range of software packages, including Maple, Mathematica, Matlab, COMSOL Multiphysics and R. Computers are replaced automatically every three years. There are 33 "Compute Boxes": powerful desktop servers on which researchers can carry out intensive computations. High Performance Computing is provided by Oxford Advanced Research Computing, the E-Infrastructure South Supercomputers, and Shaheen at KAUST. We have 11 computing officers, who support departmental IT on Linux, Mac OS and Windows.

Investment in infrastructure and facilities. In the period, the university invested £72m in a new building for the Mathematical Institute, the Andrew Wiles Building; this unites the department under one roof for the first time ever. With 310 offices and a suite of three lecture theatres, ten seminar rooms including a dedicated taught course centre, a facility to replace our current "wet lab", and a range of meeting rooms, it is a magnificent new home for mathematics at Oxford. With the capacity to host major events such as SPA15 and BAMC16, the building also provides an exciting new resource for UK mathematics.

The University has identified a building to provide a new home for the Department of Statistics, which is currently spread over four buildings. It will comfortably accommodate the whole department and provide generous teaching and interaction space. It is ideally situated, near Computer Science, Engineering, Mathematics and Physics and a short walk from the biological sciences buildings that have served so well in fostering current interdisciplinary research activity.

The research funding portfolio. We have secured £64M of external research funding during the period, more than double the corresponding amount reported in RAE08. Of this, £21.3M is from UK Research Councils, £9.5M from UK Charities, £10.9M from the EU, £14.6M from KAUST, £3.5M from industry and £4.2M from other sources.

This external funding has been instrumental in driving forward our research. Our strategy for the KAUST grant, which funded OCCAM, was to focus on bringing young mathematicians to Oxford and exposing them to problems from across the scientific arena. We made seven RF and 33 PDRA appointments, funded 15 doctoral students (12 fully) from the grant, and leveraged its funding to obtain support for 17 additional RFs and PDRAs and 15 more students. We used the funding flexibly, extending support for projects that went especially well. Six OCCAM faculty were fully funded by the grant (five new appointments) and four were partially funded. The investment in people was supplemented by a vibrant visitor programme (378 visitors; £1.42M support) and events (inc. 14 overseas workshops and meetings and four graduate modelling camps; £958K).

Our EPSRC Platform Grant in Mathematics has been used to support 29 long-term visits and 13 workshops, a range of activities to promote number theory following the arrival of Wiles, a high-risk high-return project developing a relationship with MathWorks, and pump priming for an interdisciplinary project in mathematical biology.

Research funding applications are supported by a Research Facilitation team, which proactively seeks out opportunities for funding and assists faculty with the preparation of research grant applications. Proposals over £15k undergo an internal system of peer review and mock interviews are organised for those attending interviews to secure personal fellowships or large grants.

Our faculty have been extremely successful in securing funding for individual research projects, typically employing a single PDRA. We are now encouraging and supporting them in applying for longer and larger grants, as vehicles for taking forward their whole research programme in a coordinated way. A major priority will be to renew or replace our KAUST grant and to diversify core funding for the OMI by securing grants from other parts of the financial services industry. We will seek major funding for our interdisciplinary activities in areas including biological sciences, climate research, energy, and machine learning. At the same time, we aim to broaden our industrial portfolio and secure funding for programmes in emerging themes such as filtration.

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Consultancies and professional services. All faculty members are permitted to undertake up to 30 days of consultancy per year, often organised through Oxford University Consulting, the University's consulting arm. In the period, our faculty have undertaken 54 consultancies. As an indicator of activity, 21 Non-Disclosure Agreements have been signed with companies during the period not including those associated with doctoral student and PDRA projects.

The Statistics Department has a small in-house consultancy service, currently tackling around 60 problems per year, brought by researchers from across the university. There is an urgent need to expand this resource to meet growing demand and this will be an integral part of the strategy for the department over the next few years.

e. Collaboration or contribution to the discipline or research base

Academic collaborations: Our individual researchers have extensive international networks of collaborators: 92% of our submitted faculty have published a paper with an international co-author during the REF period, and 100% have presented their results in an overseas seminar or conference. These activities are underpinned by our generous research support funds and extensive visitor programme (see Section c).

We have both formal and informal collaborations with other institutions including 40 jointly held research grants. Other major links include the Oxford-Princeton networks in Complex Fluids and Mathematical Finance, which each have yearly workshops alternating between Oxford and Princeton; the HAPMAP and 1000 Genomes projects, which involved researchers from six and seven countries respectively; PIRE (the Partnership in International Research and Education at the triple point between mathematics, mechanics & materials science); the CNRS-Oxford Collaboration Scheme; the IHES, UC Berkeley, Oxford & Aarhus Centre of Excellence in Geometry, which supports graduate students and a visitor programme; and the University of Technology Malaysia-Oxford Strategic Alliance in Industrial and Applied Mathematics. A less formal link is the "Nigel Hitchin Laboratory", created in 2012 at the Instituto de Ciencias Matemáticas in Madrid to foster interaction and collaboration between the geometers in Oxford and Madrid.

Collaboration outside academia: Our wide involvement with industry and government agencies is described in more detail in the Impact Template. During the REF period, 31 of our faculty have written papers with non-academic co-authors. We have engaged with over 143 companies. Of these, 11 companies have sponsored 29 industrial projects for the Mathematical Modelling and Scientific Computing MSc. We have secured funds for 12 new CASE awards from 10 companies (with 18 awards active during the period), two partially funded studentships, and 10 SABS-IDC studentships from five companies. A further three doctoral studentships and six PDRA positions have been fully funded by industry. We run a regular Industrial and Interdisciplinary workshop series during term. There have been 99 sessions in total, with 56 sessions covering 17 other disciplines, and 43 sessions with 20 companies and two hospitals. As an exemplar of our approach to industrial collaboration, our deepening relationship with Pall Corporation is described in the impact template.

We are at the heart of three national structures that support collaboration. The Mathematics in Industry Information Service (www.maths-in-industry.org) is run from the Mathematical Institute, and provides information on upcoming industrial mathematics activity as well as providing a repository for reports from Industrial Study Groups. The sister site for Mathematics in Medicine is hosted by the Mathematical Institute and was run by the department until 2010. The Smith Institute Knowledge Transfer Network for Industrial Mathematics is an external initiative whose mission is to deliver improved industrial performance through innovation and new collaborations, by driving the flow of people, knowledge and experience between businesses and the science base. The Director, Scientific Committee Chair and one of the Technology Translators are based in Oxford.

Interdisciplinary research. We have a strong tradition of interdisciplinary research and fostering it remains a strategic priority. Vitality of research across the UoA is sustained through collaborations with a huge range of disciplines, spanning physical, biological and social science and medicine. For example, within Oxford, we collaborate with 29 other departments. In total, 64 of our faculty have co-authored papers with researchers in other academic areas during the REF period.

These collaborations drive important new research directions for all parties. As a specific example, with researchers at the Wellcome Trust Centre for Human Genetics, our pioneering work mapping recombination hotspots along the human genome identified a string of 13 DNA bases now known as a Myers motif. Our identification of a specific protein that binds to this motif has resulted in a fundamental advance in our understanding of the initiation of recombination and has led to world-wide experimental activity to understand the function of this protein in humans and other species.

Formal initiatives: We are involved in numerous multidisciplinary initiatives within Oxford. Examples include: the Wellcome Trust Centre for Human Genetics; the OMI; OCCAM; and Oxford Solid Mechanics, a five-department initiative, founded and resourced by members of the Mathematical Institute. Activity in mathematical physics seamlessly unites researchers from the Mathematical Institute and Department of Physics; and the CABDyN Network coordinates activity in complex systems. Proactive involvement with Oxford's DTCs has catalysed new collaborations in biology and medicine; the DTCs involve 24 departments. Researchers from across the mathematical sciences are supported by projects in the University-wide Oxford-Martin School.

Support Mechanisms: Our Research Liaison Officer's remit is to link mathematical scientists with other disciplines and industry, for example by coordinating weekly Industrial and Interdisciplinary workshops at which scientists or industrialists present open problems. These often develop into research collaborations (from MSc projects to interdisciplinary grants and collaborative networks). The University Based Impact and Innovation team facilitates large-scale cross-department research activities involving external funders such as the BP-Oxford initiative described in our Impact Template. A university-wide initiative to promote interdisciplinary research themes links researchers from across the university in areas such as Energy and Climate research.

Our seminar series provide ideal grounds for interdisciplinary activity. For example, both the Mathematical and Computational Biology seminar and the Logic seminar are joint activities of the Mathematical Institute and the Department of Computer Science; the Numerical Analysis Seminar is organised by the Mathematical Institute and the Rutherford Appleton Laboratory. The Oxford-Man Institute organises cross-disciplinary seminars in quantitative finance, while the OCCAM Seminar and group meetings draw together researchers from four research groups in the Mathematical Institute and one from the Department of Computer Science. Seminar series such as those in Mathematical Geosciences, Mathematical Finance, and Mathematical Genetics & Bioinformatics draw both speakers and audiences from outside the mathematical sciences.

Strategy for collaboration with research users. Industry partners and researchers in other disciplines bring interesting, timely and relevant problems which often develop into collaborative research projects for which our expertise is essential. When exploring these questions, it nearly always becomes clear that they are unanswerable without widening the focus to include more fundamental mathematics. Through collaboration, we answer the research user's question while inspiring the development of novel theory. Companies often provide further direct research funding that shapes activities, as well as being partners on grant applications to external bodies, both for particular scientific projects and for broader strategic endeavours (for example, partnering in a CDT application); this is exemplified by our interaction with HSBC as described in the Impact Template.

Our research strategy is informed by viewing the whole research landscape, including our collaborations, and potential collaborations, with research users. This feeds into our staffing strategy: in the period we created three faculty positions in Industrial and Interdisciplinary Mathematics (one with a preference for research in energy) and two in Mathematical Geoscience.

Our graduate training strategy has embraced the demand for interdisciplinary research. 52 of our current students are involved in interdisciplinary projects. Our five MSc courses provide training from fundamental mathematics, statistics and computer science to the industrial interface: all foster interdisciplinarity. One of our courses is jointly organised by two departments, and all the steering committees contain research users.

Leadership in the academic community. Leadership in research and contributions by members of the UoA to the national and international mathematical community are conducted through membership of significant national and international scientific boards of conferences and scholarly

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societies, assessment of universities and other institutions, and major editorial duties for journals and book/monograph series.

Leadership roles on boards of national and international scientific organisations and institutions in the period include: SIAM President (Trefethen), LMS Presidents (Ball, G Segal), LMS President-elect (Lyons), SIAM UK/Ireland Section President (Süli), Chair of the Newton Institute Scientific Steering Committee (Ball), Chair KTN Scientific Committee (J Ockendon, Please), Executive Director of ECMI (H Ockendon), EPSRC MathSAT (Ball, Etheridge), International Council for Science Executive Board (Ball), President of Clay Mathematics Institute (Woodhouse).

18 journals have, or had in the period, editorial offices within the UoA: *Combinatorics and Computing* (Riordan), *Quarterly Journal of Mathematics* (Dancer, Heath-Brown), *Mathematische Annalen* (Hitchin), *British Society of the History of Mathematics Bulletin* (Stedall, until 2012), *Journal of Nonlinear Science* (Maini), *Applied Mathematical Finance* (Hambly, until 2012; Reisinger), *European Journal of Applied Mathematics* (Howison), *IMA Journal of Numerical Analysis* (Süli), *Archive for Rational Mechanics and Analysis* (Ball), *Social Networks* (Snijders, until 2011), *Journal of the LMS* (Batty), *Journal of Topology* (Tillmann), *Bulletin of Mathematical Biology* (Maini), *Acta Arithmetica* (Heath-Brown), *Maths-In-Industry Case Studies* (H Ockendon), *Information and Inference* (Tanner), *Mathematical Proceedings of the Cambridge Philosophical Society* (Green), *Acta Mathematica Scientia* (Chen). Our faculty collectively hold 198 other editorial board memberships.

Invited keynote lectures include: ICM (Heath-Brown, Lackenby, Maini, Riordan, Seregin, Zhou, 2010; Ardakov, Conlon, Green, Lyons, Pila, Sanders 2014), Royal Society Francis Crick Prize Lecture (McVean 2010), SIAM John Von Neumann Lecture (Ball 2012), Abel Lecture (Bridson 2009, Tillmann 2012), IMS Medallion Lecture (Lyons 2010, Holmes 2011), IMS Wald Memorial Lectures (Lauritzen 2012), Von Mises Lecture, Berlin (Ball, 2012), IMS Schramm Lecture (Lyons 2013), Mary Cartwright Lecture (Etheridge 2011), Genetics Society Balfour Lecture (Myers 2013), Andrzej Jankowski Memorial Lecture (Joyce 2011), DiPerna Memorial Lectures, UC Berkeley (Chen 2009), Emmy Noether Lecturer (Tillmann, 2009), Cahit Arf Lecturer (Pila 2011), MCQMC Plenary Lecture (Giles 2012), Congress of Bachelier Society Plenary (Zhou 2012), BAMC Plenary (Maini 2010, Trefethen 2013), Chern Lectures, UC Berkeley (Hitchin 2013), Schrödinger Lecture (Bridson 2011).

Prizes won by current UoA10 members include: LMS Senior Whitehead Prize (Pila 2011, Kirwan 2013), LMS Polya Prize (Heath-Brown 2009; Segal 2012), LMS Naylor Prize (Maini 2009, McLeod 2011, Trefethen 2013) LMS Whitehead Prizes (Drutu 2009, Waters 2012, Alday 2013, Sanders 2013), Royal Society Sylvester Medal (Ball 2008, Segal 2010), Royal Society Copley Medal (Penrose 2008, Cox 2010), Royal Society Faraday Prize (du Sautoy 2008), European Prize in Combinatorics (Conlon 2011, Sanders 2013), Ho-Am Prize in Science from the Samsung Foundation (Kim 2012), IMA Gold Medal (Trefethen 2011), Philip Leverhulme Prizes (Erban 2010, Marchini 2012, Tanner 2008), Royal Statistical Society Guy Medal in Silver (Ripley 2013), Royal Statistical Society Guy Medal in Bronze (Holmes 2009), Annales de l'Institut Henri Poincaré Prize (Tarres 2008, Goldschmidt 2012), Bessel Research Prize (Tillmann 2008), IMA Crighton medal (Neumann 2012), European Mathematics Society Prize (Green 2008, Sanders 2012), INFORMS Best Simulation Publication Award (Giles 2011), Bruti-Liberati Fellowships (Obloj 2011, Ruf 2013), Adams Prize (Sanders 2011), Clay Research Award (Pila 2011), Institute of Statistics Medallion (Holmes 2011), Genetics Society Balfour Prize (Myers 2012), SIAM Richard C DiPrima Prize (Macdonald 2010), Morgan Stanley Prize (Ruf, 2010).

Joyce (2012), Lauritzen (2011), Candelas, Green, and Griffiths (2010), and Tillmann (2008) were elected to Fellowships of the Royal Society, taking the total number of FRS active in the UoA to 20 (including seven emeriti). Honorary degrees have been awarded to Acheson (UEA 2012), Ball (Paris – Pierre et Marie Curie 2010), du Sautoy (Bath 2010, Liverpool 2013, Queen Mary 2012, Open University 2008), Lauritzen (Aalborg 2008) and Snijders (Paris-Dauphine 2011). OBEs were awarded to Neumann (2008) and du Sautoy (2010).