Institution: University of Oxford
Unit of Assessment: 5 – Biological Sciences
1. Unit context and structure, research and impact strategy

Our overarching aim is to facilitate transformative research in the biological sciences and maximise its impact. During the current REF period we have developed and expanded the research and impact strategies articulated in REF2014 to more effectively deliver on our objectives. We have made substantial new investments in research infrastructure and staff, and improved support for staff and students, underpinned by our pursuit of equality and diversity. We have strengthened our commitment to public engagement in research, to open and reproducible research, and to the highest standards of research integrity. Transformative research often requires interdisciplinary approaches and our research strategy aims to provide an outstanding environment for such collaborations.

Major achievements in this REF period:

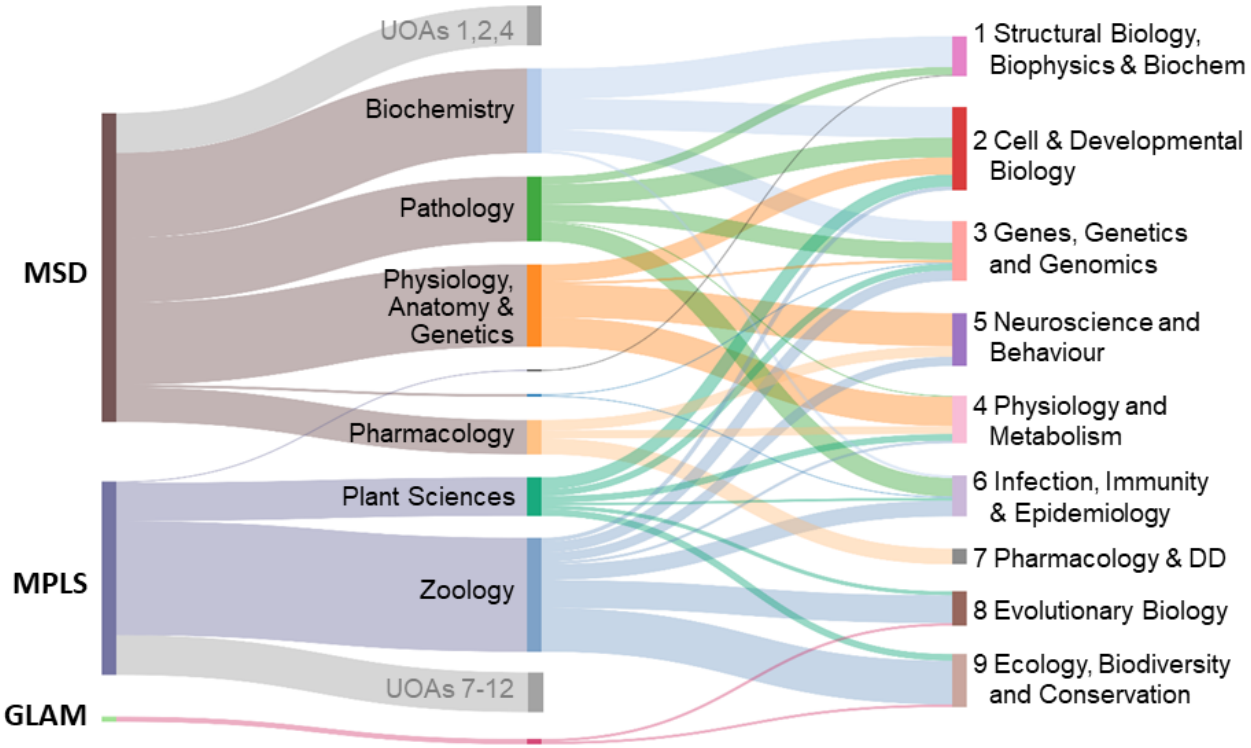
- Recruited 55 of our current ECRs and 39 more experienced researchers since 2013/14, to ensure the sustainability of our research base.
- Increased average annual grant income from research council, charities, EU government and UK industry categories by 16%, 40%, 55% and 300%, respectively, compared to the previous REF period.
- Planned and secured >£320M of investment to build three major new centres that will form hubs for new interdisciplinary research themes.
- Invested >£10M in research facilities to provide access to advanced technologies and to facilitate academic and commercial collaborations and partnerships.
- Awarded or renewed funding for nine major Doctoral Training Programmes to train the next generation of biological researchers.
- Increased commercial activity: 438 patent applications, 354 licensing/options deals, 204 Consultancy agreements and 12 companies (that collectively raised >£175M in investment and currently employ ~220 people).
- Re-invested the University's share of profits from the sale of UOA5 spin-outs *Natural Motion* and *Oxitec* (sold for $658M) in new research initiatives and graduate studentships.
- Provided the academic leadership for the University's successful bid for a devolved 'Enriching Engagement Centre' from Wellcome, to promote public engagement with research.

1.1 Structure and context

Coordination across UOA5 is provided by the **Medical Sciences Division (MSD)**, which links UOA5 to the clinical departments returned in UOAs1, 2 and 4, and from the **Mathematical, Physical and Life Sciences Division (MPLS)**, which links UOA5 to the physical, mathematical, computational and engineering science Departments aligned with UOAs 7-12 (Figure 1). Strategic leadership and administrative responsibilities within UOA5 are devolved to **six Departments** and the unit of Gardens, Libraries and Museums (**GLAM**). Our research is broadly organised into **nine Thematic Research Groups** (Figure 1) that reflect core areas of research strength and that include Centres and Institutes that are physically located within or adjacent to their host Departments. By design, these Research Groups are inclusive, with many of our researchers active in more than one, promoting collaboration and ensuring **cross-disciplinary synergy**. This environment supports flexible and sustainable research, and our aim is that while these Research Groups will evolve over time, we maintain their strategic focus and the critical mass required to attract new talent and external grant income.

This structure creates a stimulating environment that allows us to respond effectively to emerging opportunities and challenges. There is perhaps no better illustration of this than in our contributions to Oxford's research response to the COVID-19 pandemic (Section 4.8).

Figure 1: Contributions to the Unit's multidisciplinary Research Groups (right) from Departments in two Divisions and in **GLAM (left).** Breadth of ribbons denotes number of submitted researchers (headcount) by primary group, except for other UOAs where they show relationships only.



1.2 Research and Impact Strategy

The **University of Oxford Strategic Plan** outlines our institutional mission, objectives and values (see *Institutional-level Environment Statement* [REF5a, hereafter **IES**]. In UOA5, a particular emphasis in our REF2014 submission was to **increase inter-Departmental cooperation and collaboration** to better deliver on our strategic objectives, and we have made great progress in the current REF period. This is evidenced by the unprecedented level of investment in joint building infrastructure (Section 3.1) and joint research facilities (Section 3.2) and by the successful renewal or creation of several cross-departmental Doctoral Training Programmes (DTPs, Section 2.1.4). Most notably, during the current REF period UOA5 Departments worked closely together, and with other UOAs, to plan three major new research initiatives and to secure capital investments for new buildings to house them:

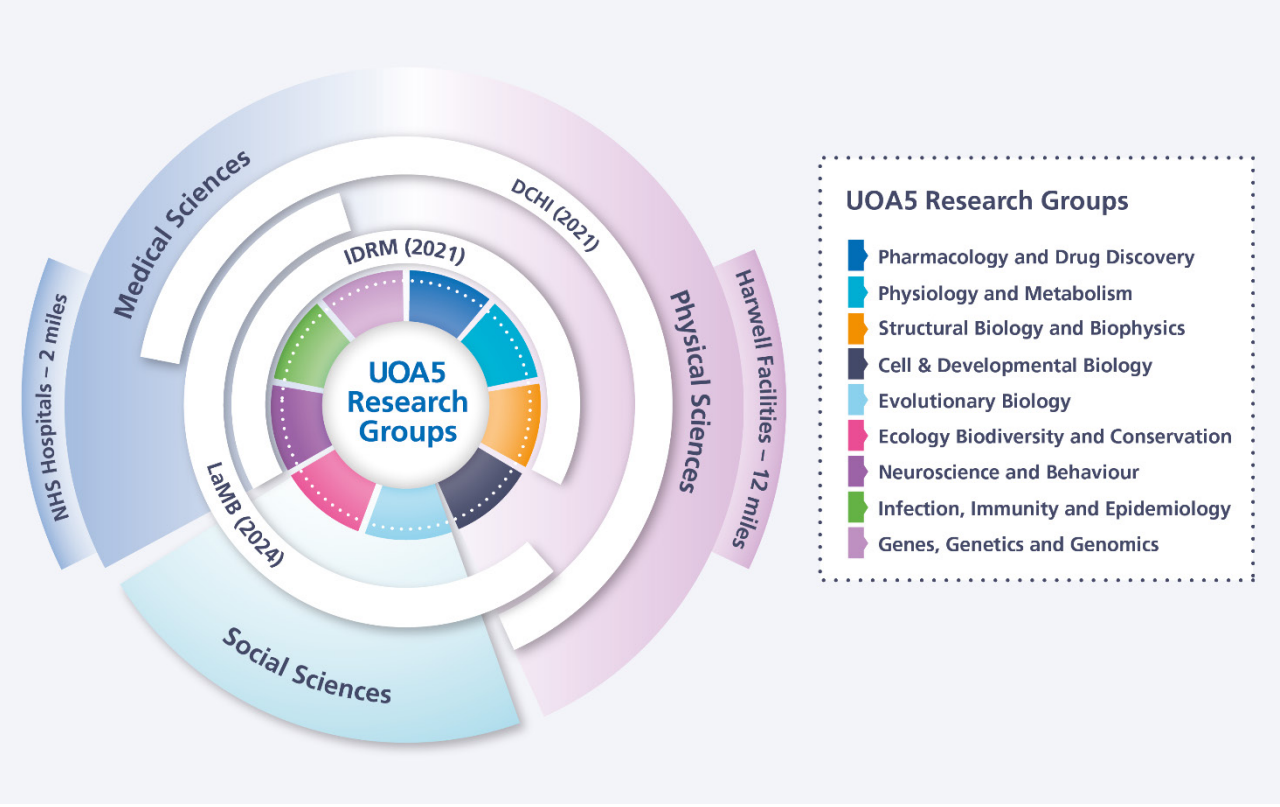
- the **Dorothy Crowfoot Hodgkin Institute** (**DCHI**; £92M, 13,000m^2 building opening in 2021)
- the **Institute of Developmental and Regenerative Medicine (IDRM**, £32M, 5,900m^2, opening in 2021)
- the **Life and Mind Building** (**LaMB**, £202M, 25,000m^2, opening in 2024).

This strategy of cooperation has supported transformative research in areas such as bacterial and viral epidemiology and pathogenesis, and fundamental structural, molecular, cell and developmental biology, and our new buildings will provide exciting opportunities for future strategic growth. For example, to emphasise fundamental biological principles, and also the 'whole biology' nature of

global challenges in areas such as biodiversity, environmental sustainability, food security and anti-microbial resistance, the Departments of Plant Sciences and Zoology will merge in 2022 to form a unified Department of Biology, and will be housed in the **LaMB**. The co-location of the Department of Experimental Psychology (UOA4) in the LaMB will generate a unique combination of expertise and the opportunity to focus on the interface between Biology and Human Behaviour in areas such as such as bio-inspired engineering ('hacking nature'), living with biodiversity, and conflict resolution. The **DCHI** will spark new interdisciplinary collaborations with researchers from Chemistry (UOA8) and Physics (UOA9) to address fundamental molecular mechanisms at the interface between the physical and life sciences, and thereby also with Computational Science (UOA11) and Engineering (UOA12). The **IDRM** will enhance our translational research capacity (another major goal articulated in our REF2014 submission), bringing together researchers from UOA5 and UOA1 to focus on interdisciplinary approaches to heart, brain and immune system development and pathology.

The LaMB and DCHI sites are located in the heart of the biological and physical sciences area in central Oxford, while the IDRM is located on the Old Road Campus site – ideally situated to promote interactions with researchers and clinicians at the Churchill and JR Hospital sites and at several research Institutes in UOAs 1, 2 and 4 (Figure 2). The opening of the Rosalind Franklin Institute (RFI) building on the Harwell Research Campus in 2021 [IES 2.5] will provide further opportunities for interdisciplinary collaborations; its focus on technology development in the life sciences synergises with our investments in bioimaging, Cryo-EM and Omics technologies (Section 3.3).

Figure 2: Schematic illustration of the cluster of UOA5 activity in central Oxford, links to other discipline groups and facilities, and the new institutes deepening those connections. (IDRM denotes the Institute of Developmental and Regenerative Medicine, LaMB the Life and Mind Building, and DCHI the Dorothy Crowfoot Hodgkin Institute).



During the current REF period, the ten strategic aims set out in our REF2014 submission have been developed and rationalised into **six strategic aims for REF2021** that are necessary to fulfil our overall mission. These are:

Aim 1: Invest in infrastructure to support transformative research
Aim 2: Support a diverse and talented pool of staff
Aim 3: Train the next generation of biological scientists
Aim 4: Maximise the commercial impact of our research
Aim 5: Maximise our Impact on Public Policy
Aim 6: Promote public engagement with research (PER)

These aims reflect our response to the University's Strategic Plan and the University's objectives in the context of UOA5. Future research and impact strategy are discussed in more detail in Sections 1.4 and 1.5, but first we describe these aims and provide examples of some of our major achievements in the current REF period. We refer where appropriate to our impact case studies (ICS) in REF3 and institutional environment statement (IES) in REF5a.

Aim 1: Invest in infrastructure to support transformative research

World-class research requires world-class infrastructure, and we strive to ensure that our facilities are modern, well-equipped, and designed to **maximise interdisciplinary interactions**.

- **Developed communal research facilities** in CryoEM, Advanced BioImaging, Molecular Biophysics, Stem Cell Research and Genome Editing, with over £10M total funding (Section 3.3). These facilities are run by expert core staff, and they allow our researchers easy access to advanced technologies. They also act as hubs to promote collaborations and partnerships locally and internationally (Section 4.1).
- **New buildings.** Strategic planning to meet our evolving needs led to the scoping, refinement and sustainable business cases for the LaMB, DCHI and IDRM buildings, which together will provide over 43,000m^2 of research space. The research mission of each benefitted from an intensive collaborative effort to identify key research themes and leadership, and ultimately enabled capital investment being committed. The size and clarity of these strategic endeavours will strengthen interdisciplinary research over the next REF period.
- **A new postgraduate college to support interdisciplinary training.** Extensive cross-Departmental and cross-Divisional collaboration led to the establishment of Reuben College [IES-3.3], sited in the heart of the UOA's Central Oxford location. This is Oxford's first post-graduate College dedicated to STEM subjects, and UOA5 researchers McKeating and Milner-Gulland were among the first Fellows to be appointed in 2019. This science-focused collegiate environment will promote interactions between UOA5 Fellows and students and researchers from other STEM subjects, stimulating the exchange of expertise and ideas across disciplines.

Aim 2: Support a diverse and talented pool of staff

We aim to nurture a diverse mix of outstanding early-, mid- and senior-career scientists working across a broad range of disciplines. Creating an environment where our staff are supported in their personal and professional development is not just a responsibility, but is essential if we want to achieve our goals. More detail is given in Section 2.2.

- **Increased leadership,** creating eight new Professorial posts to recruit and/or retain senior leadership in Immunology, Genomics, Cell Biology and Metabolism, Evolutionary Microbiology, Epidemiology and Biodiversity.
- Appointed **28 other research faculty** to help sustain and develop our nine major Research Groups (Section 1.3).
- **Strengthened career support for staff,** adopting several new practices such as inductions for all new staff and a framework for annual personal development reviews. We also focussed on improving communication and access to information. Approximately 88% of UOA5 staff said they were satisfied in their job in our most recent internal surveys.
- **Targeted support for junior researchers**, including mentors, postdoc associations and in excess of £500k seed funding to help develop ideas and independent projects.

- **Increasing staff diversity.** In REF2014 we had started on our path to advance equality and diversity, but we now incorporate this as a core strategic goal. We have adopted ambitious action plans, made training in unconscious bias compulsory for all staff and strengthened our 'family friendly' provision. As one example of outcomes, the proportion of researchers self-reporting as BAME increased from 11.6% in 2013 to 15.1% in 2020.

Aim 3: Train the next generation of biological scientists

We aim to support the UK research pipeline by training **Post-Graduate Research (PGR) students**, and a major goal in our REF2014 submission was to increase student numbers. Despite several significant UOA5 funding agencies reducing support for studentship programmes, we increased the number of students trained in UOA5 to an average of ~126 students/year, compared to ~110/year in the previous REF period. Section 2.2 gives details.

- **Renewed or initiated several Doctoral Training Programmes (DTPs).** UOA5 researchers were involved in successful renewal bids for five existing DTPs and four successful bids for new DTPs (Table 1, Section 2.2), bringing in an average of ~£15M/yr in studentship funding during the current REF period.
- **Increased internal funding for PGR students.** Some of the profits from the sale of two UOA5 spin-outs (*Natural Motion* and *Oxitec*) were used to endow in perpetuity four PGR scholarships per year in UOA5. Approximately 18% of students starting in any MSD programme in 2016-2019 received internal funding. In early 2020, the University committed to increase internal Clarendon Scholarship funding to £8.5M/yr, (an increase of £1M/yr) to help compensate for the reduction in studentship programmes from several funders.
- **Introduced additional support mechanisms for PGR students.** Supporting student health and well-being is increasingly recognised as an essential part of our mission and we have supported several new initiatives (e.g. compulsory training in student mental health issues for all PGR student supervisors).

Aim 4: Maximise the commercial impact of our research

We encourage our researchers to maximise the commercial impact of their work and to ensure they are properly supported to do so. Our ***Impact Case Studies (ICSs)*** provide examples of how fundamental research in UOA5 has been translated into patents (02MIGLUSTAT, 20FLU), licences (07BRAHMS), technologies, drugs and spin-out companies (10OXBIODYN, 11OXBIOMED, 12OXITEC) that are having a real-world impact in the pharmaceutical industry and in public health (18EPIDEM). The economic impact of several spin-out companies formed in the current REF period is highlighted in Section 4.2.1.

- **Allowed researchers time to pursue commercial activities**: our researchers can take up external appointments for up to 30 days/yr without loss of salary. In early 2020 the University introduced a scheme to increase flexibility further [IES 3.1], and a UOA5 researcher has already taken up this opportunity to devote more time to their company.
- ***Oxford University Innovation* (*OUI*):** we encourage engagement with OUI, the University's technology transfer company [IES 2.1], for example by organising monthly "drop-in" sessions in all UOA5 Departments. This has contributed to an increase in our commercial activity: during the current REF period we generated on average 64 new IP disclosures and 59 national patent filings per year, compared to 49 and 30, respectively, in the previous REF period. Currently 155 UOA5 staff are active in some form of commercial consultancy, 76 of whom first became active during the current REF period. UOA5 researchers spun-out twelve companies, raising >£175M in capital investment and employing >220 people (Section 4.2.1).
- ***Oxford Sciences Innovation* (*OSI*)** [IES 2.1]: UOA5 researchers have taken great advantage of this unprecedented commercial investment fund. For example, *Lab282*, a partnership between *OSI* and *Evotec*, funded nine UOA5 projects (total of ~£2M) to investigate potential new drug targets and *OSI* invested over £38M in UOA5 spin-outs (Section 4.2.1).
- **Established a new Translational Research Office (TRO):** Established in 2019, the Medical Sciences Division's TRO ensures researchers have access to expertise from both the academic, clinical and commercial sectors to enrich research programmes and maximise their potential for clinical uptake and commercialisation (Section 1.5).

- **Training the next generation of entrepreneurs.** Nuttall (UOA5) founded the *All Innovate* competition at the Oxford Foundry [IES-2.2], in which student teams pitch ideas (150 entered in 2019/20) to judges from OSI, The Prince's Trust and the UK Business Angels Association. The University holds annual Impact Awards in Enterprise and Innovation and in 2019 three UOA5 PhD students won a $50,000 collaboration with *Arctoris* in the International Cancer BioTarget competition.
- **The *BioEscalator*** opened in 2019 [IES-2.2] to provide space and tailored support for high growth start-ups, and UOA5 spin-outs *MoA Technology* and *Pepgen* benefit from being located there. The *Bioescalator* is already full, and its success has led to plans for *BioEscalator II* (Section 1.5).

Aim 5: Maximise our impact on public policy

Much of our research is relevant to public policy, and the expertise of our researchers means that they are often in a position of influence. Our **ICSs** 07BRAHMS, 08FORESTS, 13SEABIRDS, 14LIONS, 15LAND and 16SAIGAS illustrate how fundamental research in UOA5 is leading to changes in public policy in areas such as climate change and the protection of vulnerable plant and animal species.

- **Flexibility to encourage policy impact.** We allow our researchers to take time off from their normal duties, or to take formal secondments, to sit on panels and committees that advise Governments, NGOs or corporations on various aspects of public policy. Some prominent examples are highlighted in Section 4.3.2.
- **Balanced workloads to recognise policy work.** We recognise the importance of policy work and ensure that all researchers get credit for their efforts in this area when calculating administrative loads.
- **Encouraged new routes to policy impact.** We encourage our researchers to think innovatively about ways to maximise the impact of their work and we give them the freedom, often coupled with financial and administrative support, to explore their ideas. Some illustrative examples are highlighted in Section 4.3.3.
- **Supporting partnerships.** We benefit from the University's Oxford Policy Engagement Network (OPEN), formed in 2018, which provides support for our staff to engage with local, national and international policymakers [IES 2.3]. One of the OPEN Fellows (Kuiper) partnered with the national parks authority in Zimbabwe to tackle elephant poaching through data-driven policy development for protected areas.

Aim 6: Promote public engagement with research (PER)

We aim to engage with a broad public, to effectively explain what we do and why we do it, and also to better understand their priorities and concerns. More details are given in Section 4.4.

- Five UOA5 Departments now have an **academic or professional lead in PER**, ensuring local support for PER activities; these are also now supported by Divisional PER leads.
- UOA5 researcher Prof Alison Woollard was appointed **as Oxford's first *Academic Champion for PER*** [IES 2.2], and in 2019 she led the University's successful bid to *Wellcome* to become a devolved Enriching Engagement Centre for Public Engagement (~£1.25M); two UOA5 researchers (Maiden and Srinivas) have already received funding.
- We partner with the University's ***Gardens, Libraries and Museums* (*GLAM*)** to expand our engagement. Our *Bacterial World* and *First Animals* exhibitions, for example, each attracted >160,000 visitors at the Museum of Natural History.
- **We support Citizen Science** as a way to involve the public in our research. For example, more than a million people have taken part in *Penguin Watch* (Hart) through the University's *Zooniverse* programme (one of the world's leading citizen science platforms), resulting in real impact on public policy (ICS-13SEABIRDS).
- We encourage our researchers to use **digital media** to reach audiences that do not normally engage with academia. For example, UOA5 researchers participated in 15 Facebook Live events, generating >175,000 views.

1.3 Research Objectives and Achievements

In this section we briefly outline the broad **research aims and objectives of our nine Research Groups**, which have evolved from the ten Research Themes described in our REF2014 submission. We provide examples of how some of the strategic aims described above (such as investing in staff and infrastructure) have guided their development during the current REF period, and will do so into the future. The number (headcount) of submitted Researchers aligned primarily with each Group gives an indication of their size (noting that several researchers are active in more than one Group). Rather than provide an extensive description of research highlights associated with each Group (all represented in our REF2 submission), we briefly outline some of the research of our newly-hired staff to illustrate how their recruitment has strengthened each Group.

Group 1: Structural Biology, Biophysics and Computational Biochemistry

This Group (evolved from the REF2014 Biophysics and Structural Biology Theme) combines structural biology, biochemistry and cell biology in a quantitative and predictive fashion to explain the fundamental mechanisms of cell biological, physiological and disease processes (***30 Researchers***). We established the **COSMIC cryo-EM Facility**, raising £4.2M for staff and equipment, and facilitating several large grant awards, recruitments (in this and other Groups) and discoveries. We strengthened interdisciplinary interactions between computational and experimental biochemists, increasing our profile in this area and underpinning two large Wellcome Strategic/Collaborative awards to study membrane dynamics.
Staff Recruitment: **Bublitz** to tenured position to strengthen basic organelle biology (*Mol. Cell*, 2016), and **Shammas** and **Elliot** on Fellowships to support fundamental biochemistry of protein function (*Cell*, 2015; *PNAS*, 2017) and ubiquitination (*Cell*, 2016; *Nature*, 2016). **Seiradake** (recruited on Fellowship in last REF period) won tenured position, strengthening structural approaches to brain development and translational links to UOA1 (*Cell*, 2020).

Group 2: Cell and Developmental Biology

This Group seeks to understand how cells work, how they cooperate to build multicellular plants and animals, and how these processes are perturbed in disease (***63 Researchers***). This Group led the renewal of the Wellcome **Micron Advanced Bioimaging Strategic Award** (£4.8M, with an additional £1.2M from the University), with co-PIs in Clinical Medicine (UOA1), Chemistry (UOA8), Physics (UOA9) and Engineering (UOA12). Micron helped facilitate several major grants, staff recruitments and research discoveries.
Staff Recruitment: New appointments to tenured positions strengthen research in organelle biology: **Carvalho** (ER, *Cell*, 2014, *Mol. Cell*, 2020), **Jansen** (Centromere*, Science*, 2015, *Mol. Cell*, 2017), **Gergely** (RNA and centrosomes, *Science, 2017*) and **Kornmann** (mitochondria and ER, *JCB, 2017*). **Grueneberg** and **Ahel** (recruited on Fellowships in previous REF period) won tenured positions, strengthening cell cycle (*JCB*, 2014, 2019) and DNA damage (*Nature*, 2020, *Mol. Cell*, 2018) research, respectively. **Nott**, **Gibbs-Seymour**, **Vieira**, **Stone** and **Tyser** recruited on Fellowships to increase core Group strength.

Group 3: Genes, Genetics and Genomics

This Group aims to understand the fundamental nature of the gene and how the genome is structured and regulated in different contexts (**45 Researchers**). We invested c.£400k to establish a Next Generation sequencing and genomics Facility, partnering with the Centre for Computational Biology (UOA1). We also hosted several **major interdisciplinary collaborative projects**, such as the international C_4 rice project (Langdale) to transform rice productivity (Gates Foundation: £16M over two phases [£5.2M to Oxford]).
Staff Recruitment: Staff recruited on Fellowships in the previous REF period won tenured positions to strengthen Genomics (**Klose**, [*Cell*, 2014; *Mol. Cell*, 2019], **Gullerova** [*JCB*, 2017] and **Kelly** [*Curr. Biol.*, 2016, 2018]) or renewed Fellowships to strengthen research in DNA repair (**Cohn** [*Mol. Cell*, 2015]), non-coding RNA (**Vasilieva**, [*Genes & Dev.*, 2014]) and chromosome structure (**Akiyoshi**, [*Cell*, 2014; *Nature*, 2015]). Established **new Chair of Genetics and Genomics**.

Group 4: Physiology and Metabolism

This Group focuses on cellular and molecular aspects of oxygen and metabolic signalling to enable target discovery (***36 Researchers***), and Oxford is currently ranked #1 in World QS rankings for Physiology. We helped to establish and maintain **Oxford as a major centre for cardiac research** by contributing to the successful renewal bids for the BHF Centre of Research Excellence (£6M) and the BHF Centre of Regenerative Medicine (£2.5M), funding that underpins our plans for the IDRM. We **supported major interdisciplinary collaborative projects**, with Ashcroft leading the Integrative Physiology Initiative in Ion Channels and Disease (OXION) bid (Wellcome, £6M) (Cambridge, London and Harwell) and Paterson awarded a collaborative grant in cardiac research (NIH, $8.6M) (UCLA, Harvard, CalTech, Oregon and Nebraska).
Staff Recruitment: The recruitment of **Domingos**, **Klemm** and **Licausi** to tenured posts expanded translational research capacity—driving discoveries linking diabetes to neuro- and cardiovascular-research (*Cell*, 2015; *Nat. Med.*, 2017)—and extending our strength in oxygen metabolism to plant systems (*Nature*, 2019; *Science*, 2019). Recruitment of **de Val**, **Heather** and **Smart** on Fellowships, and **Herring** and **Lakhal-Littleton** to tenure-track positions, increased strength in cardiac metabolism (*PNAS*, 2015, 2019; *J. Clin. Invest.*, 2019) and in vascular developmental biology and regenerative medicine (*Nature Comms*, 2019). Established **new Krebs Chair in Physiological Metabolism**.

Group 5: Neuroscience and Behaviour

This Group aims to understand the evolution, development and control of behaviour, analysing how neuronal architecture encodes behaviour and impacts disease, and how organismal biology governs behaviour at individual- and population-levels (***40 Researchers***). Core funding for the Centre for Neural Circuits and Behaviour (CNCB) was renewed (Wellcome, £3.6M), and our £3.5M investment in facilities at Wytham Field Station brings new capacity to analyse flight behaviour and control, insect-plant interactions, and behavioural plasticity.
Staff Recruitment: Wellcome PRFs awarded to **Waddell** and **King**, supporting seminal work in flies (*Nature*, *2017*; *Cell*, *2018*) and non-primate mammals (*eLife*, 2019, 2020). **Vogels** and **Packer** recruited on Fellowships to increase core strength in *Drosophila* (*Nat. Neurosci.*, 2018) and optogenetics (*Nat. Methods*, 2014).

Group 6: Infection, Immunity and Epidemiology

This group studies infection from molecular and cellular mechanism to global studies of epidemiology, integrating fundamental research with clinical research and public health policy (***31 Researchers***). This Group provided important insights into COVID-19 epidemiology (generating several high-profile publications in *Science*, *Nature*, and *Cell*), with several Group members (**McLean, Dye, Pybus**) advising the UK and Chinese Governments and WHO (Section 4.3.2). Our contributions to the University's COVID-19 response are discussed in more detail in Section 4.8. We established new partnerships with the *Serum Institute of India* to develop meningitis vaccines (**Tang**) and with *MedImmune* and *Janssen* to develop a nasal anti-flu vaccine for children (**Fodor**) [ICS 20FLU].
Staff Recruitment: Recruited **Sanyal** to tenured position and **Bharat** on Fellowship to strengthen basic and applied viral and bacterial research (*Nature*, 2015; *Cell Host and Microbe*, 2018; *Cell*, 2019). **Dushek** renewed Fellowship and won tenured position, strengthening mathematical modelling in immunology (*PNAS*, 2016, 2019). Established new **Barclay-Williams Chair in Molecular Immunology**.

Group 7: Pharmacology and Drug Discovery

This Group takes an integrative approach to chemical biology, developing new drugs for research and clinical applications, and Oxford is currently ranked #1 in the QS World Subject Rankings in Pharmacology (***12 Researchers***). We successfully sought to increase funding from Pharma, e.g. a new £1M research award from *Pfizer* (**Platt**) in 2020 to validate novel targets for Parkinson's Disease. Our investment in facilities and drug-discovery platforms allowed our researchers to support the COVID-19-Moonshot project, initiated by the *Structural Genomics Consortium* in Oxford and involving >400 scientists worldwide to rapidly generate and test potential anti-COVID-19 therapeutics (Section 4.8).

Staff Recruitment: The appointment of **Potter** to a tenured position and **Lanyon-Hogg**, **Timm** and **Viney** to Fellowships significantly increased core strength in medicinal chemistry (*J.Med.Chem.*, 2017; *Nat. Chem.*, 2019). The expansion of **Russell**'s (UOA8) base in UOA5 increased depth in chemical biology and strengthened collaborations with Chemistry.

Group 8: Evolutionary Biology

This Group takes an integrated approach to understanding organismal diversity from genomes to populations, and exploits the evolutionary insight to design novel technology, inform disease control and address global problems (***26 Researchers***). The merger of the Departments of Plant Sciences and Zoology in 2022 will strengthen interactions between our plant, microbial and animal evolutionary biologists. This will be supported in the next REF period by a Centre for antimicrobial resistance research, a collaboration with Chemistry (UOA8) that will seek to deliver evolutionarily-proofed solutions to antimicrobial resistance in human health & agriculture.
Staff Recruitment: Strengthened research in evolutionary epidemiology & microbiology with tenured posts for **Dye** (epidemiology and evolution of pandemics [*NEJM*, 2014; *Science*, 2020]), **Foster** (ecology of the microbiome [*Science*, 2015, *Nature*, 2016]), **Richards** (comparative genomics [*Nat. Micro.*, 2019]), and **Verd** (evolution of gene networks [*PLoS Biology*, 2018]).

Group 9: Ecology, Biodiversity and Conservation

This Group (evolved from the REF2014 Ecology and Conservation Theme) takes an integrated approach to understanding diversity and interactions among species from microbial to global communities (***40 Researchers***). We invested £3.5M in research facilities at Wytham Field Station and Wytham Woods. These woods are one of the most valuable research woodlands in the world, offering long-term ecological data gathered over many decades. This investment allowed improvements in molecular, physiological and behavioural labs, constant environment rooms, freshwater and saltwater aquaria, field laboratories and accommodation for visiting researchers.
Staff Recruitment: Enhanced research strength in global ecosystems and ecology with tenured academic posts for **Davis** (*Nat. Food*, 2020), **Jeffers** (*J. Ecology*, 2015), **Knowles** (*ISME Journal*, 2015), **Willis** (*Nature*, 2016; *PNAS*, 2020) and **Wright** (*Nature*, 2015; *Curr. Biol.*, 2018).

1.4 Future Research Strategy

As we move into the next REF period we will continue to develop the aims articulated in Section 1.2. within the context of the University's evolving Strategic Plan. Here, we focus on some specific future challenges and opportunities and the ways we plan to address them.

- **Maximise the potential of our new buildings.** While the current REF period has seen unprecedented investment in new buildings, we need to populate these buildings with the right mix of staff and projects to ensure that their impact is greater than the sum of their parts. The close cross-Departmental cooperation developed during the planning of these projects will continue, and robust and transparent mechanisms (e.g. scientific advisory boards) are evolving to guide future strategy.
- **Recruit senior leadership.** We will be appointing >10 Professorial posts in the next 2-3yrs due to retirements. Replacing this many senior staff will require strategic thought, but provides opportunities to refresh our leadership and bring in expertise. We will focus on areas that fit with our evolving strengths and investments and that are likely to see increased funding opportunities. We will coordinate appointments to maximise synergy across UOA5, and our new research buildings provide excellent research space and facilities, which will help to attract new faculty.
- **Respond to changes to our core research funding.** We have identified two important changes that are likely to impact the way our research is funded: (1) Brexit; (2) The new Wellcome funding strategy focused on infectious disease, mental health and global warming. We will mitigate potential risks by maximising our opportunities to attract funding from existing major sources (Section 3.1), and by diversifying our sources (e.g. by increasing funding from industry and philanthropy). As just one example, we see great potential for growing our funding in infectious diseases, which fits well with Wellcome's new priorities and builds on existing strengths and initiatives (e.g. antimicrobial resistance research (Section 1.3, Groups

6 and 8). We also see potential to forge new partnerships in this area through the Oxford Martin School programmes in Pandemic Genomics and Antimicrobial Resistance [IES 2.6], as well as through the University's antimicrobial resistance monitoring network in Vietnam [IES 2.1]. A new Institute for Pandemic Preparedness in Oxford is already in planning stage, led by colleagues in UOA1.

- **Improve sustainability of research funding.** A problem that has become more acute over the current REF period is that charity-funded grants attract decreasing levels of Research England charity QR support. Thus, as our success in obtaining these prestigious grants has increased, so has the financial challenge of supporting them. We will continue to coordinate with other parties to address this challenge, to diversify our funding sources, and to ensure costs of research are recovered more sustainably.
- **Increase equality and diversity.** Current strategies to address these issues are set out in Section 2.3, but recent public debate, and our internal reflections, have highlighted how much remains to be done to promote and support scientists from under-represented minorities. We are committed to driving genuine change in the next REF period.

1.5 Future Impact Strategy

Our aim to support the most important and innovative research irrespective of any immediate commercial benefit is enshrined in the University's Strategic Plan. As set out in Aim 4 (Section 1.2), however, we actively encourage our staff to explore the potential commercial impact of their work and we believe there is scope for significant expansion of these activities. We will enhance our capability to partner with external investors and companies, providing easier access to commercial financing and expert advice. Here we highlight our current provision and some specific future plans.

- The **Business Partnerships Office** support the diversification of research income by securing research partnerships and funded projects with large and small businesses and securing access to 'in-kind' research resources, proprietary technologies and tools. The office also delivers a range of academic-industry knowledge exchange, innovation training and business networking opportunities, facilitates the presence of visiting industry fellows and explores opportunities for co-localisation of companies on campus.
- To maximise the translation of our world-class discovery science portfolio we established a **Translational Research Office** in 2019 (£200k/year, 3.5 FTE). It provides support to early stage translational projects, creating a pipeline of opportunity for investment and commercial uptake. The TRO ensures researchers have access to expertise from both the academic, clinical and commercial sectors to enrich research programmes and maximise their potential for clinical uptake and commercialisation. 18 projects in UOA5 have already received support from the TRO.
- **Developing a better understanding of intellectual property.** An understanding of IP, and how it enables commercialisation, is essential if our researchers are to identify and exploit commercial opportunities. Through targeted workshops and seminars we will encourage our researchers to take greater advantage of the expertise available in our Research Services, Business Partnerships and Translational Research teams so that commercialisation of research follows more smoothly.
- **Nurturing new spin-outs.** As the *BioEscalator* building is already full, the University plans for an Oxford Innovation District adjacent to the Churchill Hospital site that will house *BioEscalator II*. Our recent spin-outs are described in Section 4.3.1.
- **Supporting our companies as they grow.** Several of our more established spin-outs (e.g. *Oxitec* and *Oxford BioMedica,* [ICSs 12OXITEC, 11OXBIOMED]) are now located on science parks in Oxfordshire. This enables us to maintain close scientific connections, which benefit both the company and our academic environment. The University's close involvement in OxLEP [IES-2.5] will help ensure that there is sufficient local capacity to support our successful start-ups as they mature and expand.
- **Supporting diversification of entrepreneurs.** Internal data reveals that women and BAME staff are under-represented in our commercial activity, so we are not making the most of all our talent. We will address this by engaging with underrepresented staff to better understand the barriers they face, and by addressing this imbalance in our internal support mechanisms (for example, committees that award seed funding).

1.6 Openness and integrity in research

1.6.1 Facilitating an open research environment

We aim to ensure that our research is made freely available to as wide an audience as possible and we have taken several measures to support this goal in the current REF period. We support all **Open Access expectations from relevant funding agencies,** encouraging and facilitating our staff to make their work OA wherever it is published.

- We have made increasing use of our repository, the ***Oxford Research Archive*** [ORA; IES-2.4], to make our doctoral theses, published papers and datasets freely available to all. 92% of papers published during 2019 were OA by some route, including 69% via deposit to ORA. 78 datasets were also deposited.
- UOA5 supports the University's ***'Open Access Week'***, by hosting and encouraging attendance at 'townhall' meetings where experts discuss the latest OA issues (recent topics includes Plan S and cOAlition S, promoting a research culture that understands and embraces OA.
- Four of our faculty serve as Reviewing Editors and/or Editorial Board Members for ***eLife***, and seven as Section Editors or Editorial Board Members at various ***PLoS*** journals, all publishers that are major promoters of the OA publishing movement.
- Working with volunteers from the Oxford Biomedical Research Centre (BRC), the COVID Moonshot team (Zitzmann, UOA5) generated a website that makes all data on **the efficacy of potential COVID-19 drugs** in cell-based assays **immediately open to the research community** (sarscov2.assaytracker.net/, Section 4.8).

1.6.2 Ensuring research integrity

It is crucial that our research is conducted with integrity, and is seen to be so. The University supports the **UK Concordat to Support Research Integrity** [IES 2.7], and we have instigated several practices and initiatives to support this goal during the current REF period.

- All our students receive **compulsory training in aspects of research integrity**, including plagiarism, and ethics in laboratory practice and data publishing. These most often include small-group discussions where these issues can be explored informally and in depth. This policy was extended to all researchers in 2020.
- **We encourage our researchers to manage data in an open and transparent manner.** For example, the Divisions together fund a *LabArchives* licence and support team to help labs move to electronic notebooks, and we hold workshops and seminars in UOA5 to encourage labs to do so. So far 491 researchers in UOA5 labs have adopted this technology (£22k pro-rata).
- We provide our researchers with expert assistance to ensure our research complies with all appropriate **ethical and legal obligations and standards.** Advice is initially provided within Departments at an early stage in the research project cycle, and formal issues of ethical and legal compliance, especially at contract stage, are managed by experienced teams within the University's Research Services unit [IES 4.1].

1.6.3 Reproducible research

Ensuring experimental reproducibility is an important consideration in the biological sciences, and ***Reproducible Research Oxford (RROx)*** is the local node of the ***UK Reproducibility Network (UKRN)*** tasked with coordinating our activities in this area [IES 2.4]. Two examples illustrate how UOA5 researchers are already playing an important part in promoting experimental reproducibility:

- UOA5 biochemists contributed to a successful application to the EPSRC to renew the ***Sustainable Approaches to Biomedical Science: Responsible and Reproducible Research (SABS:R3)*** DTP. This is a collaboration between the University and 22 partners (including AstraZeneca, GE Healthcare and Microsoft Research) that will train a cohort of researchers to apply robust computational methods to biomedical datasets. Having some of these students embedded in UOA5 research groups will promote more reproducible methodologies and better practice throughout the biological sciences.

- Biomedical laboratories routinely perform cell culture to produce a cellular environment that is precisely defined, and a fundamental variable is its pH. Pavel Swietach realised that **reporting standards** for pH are inadequate and often prone to artefacts that increase noise, compromise reproducibility and can lead to data misinterpretation. He therefore formulated **evidence-based guidelines** on how to set, manipulate and maintain pH in culture systems (Michl et al., *Comm. Biol.*, 2019). His work is now supported by an ERC Consolidator Award (€1.9M) and will set new standards for cell culture work that will improve reproducibility in this important area.

2. People

We aim to sustain a diverse mix of outstanding researchers and to provide them with the physical infrastructure and nurturing environment that allows them to flourish. This goal is central to our mission to deliver transformational research and to maximise its impact.

Modern research is rapidly changing, and an important element of our strategy that is relevant to all our staff and students is to provide them with the time and resources to **continually develop and enhance their skills**. We provide training to improve research and/or transferable skills (e.g. computer programming, bioinformatics) and enhance career progression (e.g. presentation skills and CV preparation). All staff and students also have access to the University's ***Careers Service*** [IES 3.3]. Some of the more specific ways in which we support the development appropriate to different career stages are highlighted in the relevant sections below.

2.1 Staffing strategy and staff development

We employ a sustainable but dynamic mix of early-, mid- and senior-career scientists, with both sufficient turnover (through staff retiring or progressing to new posts elsewhere) to continually refresh our research-base, and sufficient stability to maintain strength across our core Research Groups. Although we set no specific targets for the demographic profile of our staff, we have maintained what we believe is a healthy rate of turnover at all levels through the current REF period.

Our increase in staff numbers over the previous REF period is driven in part by our success in creating new posts and also in attracting talented junior staff who acquire competitive independent fellowships. In line with the **University's Code of Practice (CoP)**, a consistent set of indicators was used to identify *all* researchers with responsibility for undertaking independent research, regardless of grade or job title. Thus, the REF definition of an **Early Career Researcher (ECR)** amongst Category A staff covers a range of types of post; in what follows we therefore use the term **junior research faculty** to denote those on academic posts and longer-term fellowships (typically 5 years' duration) who have not yet secured tenure. 79 submitted researchers (REF1) are formally ECRs by the HESA definition. The balance between Category A staff on long-term and short-term contracts is largely determined by the ratio of types of posts: 45% of our Category A eligible staff are on fixed-term contracts.

2.1.1 Staffing strategy

Our tenured and tenure-track research faculty broadly comprise **Statutory Professors (SPs)**, **Research Professors (RPs)** and **Associate Professors (APs)**. In addition, **Independent Research Fellows (IRFs)** starting their own independent groups are given equivalent input to decision-making and access to facilities and space allocation as APs. We currently have ~450 **post-doctoral researchers (PDRs)** working in UOA5 departments, playing a crucial part in our research and impact activity. Our strategy and procedures for hiring research staff are described below.

- **SPs and APs** are appointed by a statutory committee with broad representation including external representation. While SPs are typically in major fields as set out in University statutes, these titles are interpreted broadly and the fit to strategic research priorities is

considered. For APs, departments typically undertake a planning and consultation exercise to identify strategic priorities and their overlap with educational requirements before advertising. SPs can receive generous start-up packages (up to £1M).

- **RPs** are appointed by the University Senior Appointments committee when there is a strong strategic and financial justification for the retention of key staff or for recruitment into a particular area. Nine such appointments were made in the current REF period.
- **APs** are appointed for an initial period of five years, given support and mentoring, and then confirmed in post after a tenure decision during that period [IES 3.1]. During the current REF period all UOA5 APs were confirmed in post, where necessary with an extension to the 5-year period and additional support.
- **IRFs** are usually recruited into an area of strategic interest. Selection is usually by open competition, and successful candidates then apply for Fellowship support and join the faculty if successful. Individual details vary, but senior IRFs (such as Wellcome PRFs or SRFs) usually have their posts underwritten, while more junior IRFs (such as Sir Henry Dale Fellows) may have commitments of 1-2 years of salary support at the end of their Fellowship. Due to our UOA's size, appropriate tenured or tenure-track positions in Oxford arise frequently, providing opportunities for IRFs to continue their careers within Oxford.
- **PDRs** are typically supported by funding awarded to a research faculty member, for which they are appointed in open competition after interview by an appropriately constituted and trained interview panel. They are initially employed for a probationary period, and then confirmed in their full contracts that are fixed to the grant award period. A smaller number are at the very earliest stages of their independent research careers, having won postdoctoral fellowships (usually 1-3 years) to develop their own ideas, drawing on the facilities and mentoring of a host research group.

Although this staffing structure allows many of our researchers to progress their careers within Oxford, we view it as an equal success when staff are recruited to prestigious positions in the UK and around the world. Examples include: Lea (NIH, USA), Dolan (Vienna), Ponting (Edinburgh), Marques (Lausanne) and Bub (Canada), while Malloy, Gluenz, Castello, Oliver, Cantley, Vogels and Kirchhelle are examples of staff recruited on IRFs who have been appointed to tenured positions elsewhere. Many of our PDRs have left Oxford to establish their own independent groups, e.g. Bauer (Crick), Beccano-Kelly (Cardiff), Boemo (Cambridge), Cheung (Yale-NUS), Conduit (Cambridge).

Heads of Department (HoDs) are drawn from within the department's academic staff, with selection either by interview panel or internal election, chaired or confirmed by the Head of Division. Most HoDs are appointed for five years, extendable for a second term. **Senior leadership** is strengthened by Associate Heads of Department with specific portfolios (e.g. Research, Finances, People), and such posts often (but not inevitably) provide future HoDs, enabling long-term strategic vision to be developed and carried through.

2.1.2 Staff development

The University is a signatory of the ***Concordat to Support the Career Development of Researchers***, which provides a framework for our policies on Environment and Culture, Employment, and Career Development. Our compliance is evidenced by the annual award of a European Commission ***HR Excellence in Research Award*** since 2012 (most recently renewed in 2020 [IES 3.4]. Encouragingly, **88% of UOA5 staff expressed overall satisfaction** in their job in our latest internal survey (2018). We have implemented several policies in the current REF period to improve staff support and development.

- **All Departments provide an induction package for new staff**, where they are provided information about the extensive support and training resources available. For example, several Departments fund their junior faculty to attend the EMBO *Lab Leadership course,* and several have initiated "Post-Doc Pal" schemes, where new PDRs are paired with an experienced PDR from another group to accelerate integration. New staff will also meet their HoD or line manager to discuss in an open and supportive manner the contributions that they should be aiming towards.

- **Progress for all research staff is monitored** through mandatory annual Personal Development Review meetings focused on career support and progression. Both participants sign off on a joint meeting summary that will include clear objectives for the coming year. Additional responsibilities such as workpackage roles on large grants are identified and supported.
- **All junior faculty are appointed an academic mentor,** who they meet regularly to review career progression, identify support and training needs, and discuss the practicalities of running a research group (e.g. the mentor will often help with the interviewing of PDR and DPhil student candidates).
- **Most UOA5 Departments have established Post-Doc-Associations**. These support their members in many ways, e.g. several Associations now provide a handbook as part of the PDR induction package, and several have organised peer-mentoring groups that meet regularly on their own and with an assigned PI to discuss career issues. This provides a "second advisor"—someone who knows the PDR well and can provide a meaningful job reference.
- **Fixed-term contracts** are used only where there are transparent, necessary and objective reasons to do so, which must be justified if renewed (45% of submitted staff and 92% of all research-only posts). Open-ended contracts are used where there is expectation of continuing external funding and need for the post (18 posts in UOA5 at the census date). Planning for the end of fixed-term posts and options for next steps forms part of the Personal Development Review.
- We provide **early opportunities to win research funding**: our PDRs can apply for modest grant funding from several sources to expand their projects with a specific piece of work, including the University's *John Fell Fund* [IES 2.1] (46 awards, total £319k) and the *Wellcome Trust ISSF* (5 early-career awards, £250k), and the *CRUK Development Fund* (4 awards to PDRs). This provides experience in grant writing and management as well as pump-priming further research.
- We encourage all staff to make the most of the University's *People and Organisational Development* team [IES 3.1] and fund access to the **online platform** *LinkedIn Learning* (formerly *Lynda.com*).
- **We help our PDRs to apply for fellowships and independent positions**. Our PDRs have extensive opportunities to teach undergraduates, providing valuable teaching experience to boost job-competitiveness. Detailed advice is given on fellowship opportunities. The PDR's PI or mentor will usually provide comments on any job applications and/or organise mock job interviews with other relevant PIs.

2.1.3 Study leave, sabbaticals and exchanges

It is our policy to support staff wherever possible to develop their skills and promote their careers through interactions with other Institutions.

- **We encourage our research faculty to take sabbaticals** from their teaching and administrative duties. All tenured and tenure-track and full-time/part-time faculty are entitled to one term of sabbatical for every six terms of service on full pay, with no requirement to raise any funding for a replacement [IES 3.1].
- As described in Section 1.2, our faculty can take **30 days leave from their duties at full pay** to pursue commercial or public policy work, and the recently introduced entrepreneurial leave scheme [IES 3.1] allows our staff to reduce their FTE commitment to more intensely pursue commercial activities.
- Several of our staff have prominent roles as advisors to Government or various public bodies and, where appropriate, we have worked with them **to formalise secondments** that allow them to concentrate on these important activities. For example, in 2019 Prof Dame Angela McLean was seconded for four days a week for three years to the Ministry of Defence as their Chief Scientific Advisor.

2.1.4 Staff reward and recognition

We have several schemes in place to reward staff for their academic achievements.

- Senior faculty can be nominated for a pay award through the **Professorial Merit Pay (PMP) scheme** [IES 3.1].
- We operate an annual review where staff are nominated for the **award of a Professorial, AP or University Research Lecturer title**. These awards recognise excellence in research, teaching and good citizenship and are assessed by a Divisional Committee. Since 2017, Professorial title awardees are eligible for the PMP scheme. In the current REF period, UOA5 staff were awarded 19 Professorial and 25 AP titles.
- **We run an annual Reward and Recognition Scheme,** open to all non-faculty staff, in which staff are nominated (usually by their PI, but they can also self-nominate) for either a one-off payment or for a permanent single point increase in their pay spine. Nominations are judged by a Departmental panel and approved by a Divisional Committee.
- The Vice-Chancellor's **Innovation Award scheme**, introduced in 2018, showcases excellence in achieving impact from research. In 2018, Highly Commended awards were given to Howarth as an Inspiring Leader, and to Lucey in the Early Career category. A new category of Policy Engagement was added in 2020.

2.1.5 Clinical Academics

In UOA5 our clinical academic with clinical responsibilities (Hassan) is fully integrated into his UOA5 Department in terms of space allocation and the benefits and responsibilities described above. As the Directorate Lead for Oncology in Oxford University Hospitals NHS Foundation Trust, Hassan has an important role in coordinating basic cancer research in UOA5 with the more translational work in UOA1. In addition, several academics in UOA5 have formal roles in advising our clinical colleagues. For example, Tang sits on the Steering Committee of the NIHR Biomedical Research Centre (BRC [IES 2.3]), Robbins is co-leader of the BRC Respiratory Medicine theme and Herring sits on the Advisory Board for the BHF Centre of Research Excellence. Our strong translational links with clinical colleagues is also evidenced in our Impact Case Studies (02MIGLUSTAT, 18EPIDEM and 20FLU) and in several of our spin-out companies (4.3.1).

2.2 Post-graduate research (PGR) students

During the current REF period we trained an average of 126 PGR students per year. The majority of our students are recruited either to 4-year interdisciplinary DTPs coordinated by the MSD or MPLS **Doctoral Training Centres (DTCs)**, or directly to individual projects through individual Departmental Studentship competitions. Admission to these programmes is competitive: for 2019 entry (the last year for which full datasets are available), 402 students applied to the MSD DTC (funded offers, multiple UOAs) and 482 to individual UOA5 Departments.

2.2.1 Doctoral programmes

The main DTPs relevant to UOA5 researchers are summarised in **Table 1,** predominantly offering funded places. Note that researchers from several UOAs are associated with most of these programmes, so not all of the students on every programme are trained in UOA5.

A further 5-10 studentships in each Department are funded by various other sources (e.g. UKRI, industry and internal sources, such as the studentships supported by the proceeds of the sale of *Natural Motion* and *Oxitec* [Section 1.2, Aim 3]).

Table 1: Major DTP Programmes relevant to UOA5

Programme	Main Funder	Active in REF Period	Annual Funding (approx)	# students per year (average)
Chromosome and RNA biology	Wellcome	2013-19	£1.0M	5
Infection, Immunology and Translational Medicine	Wellcome	2013-19	£1.0M	5
Neuroscience	Wellcome	2013-19	£1.0M	5
OxIon	Wellcome	2013-19	£1.0M	5
Cellular and Structural Biology	Wellcome	2013-24	£1.1M	5
Chemistry in Cells	Wellcome	2020-24	£1.1M	5
Doctoral Training Partnership	MRC	2013-24	£1.3M	18
Interdisciplinary Bioscience	BBSRC	2013-24	£2.6M	24
Environmental Research	NERC	2013-23	£2.7M	16
Cancer Science	CRUK	2019-23	£2.1M	11
SABS:R^3	EPSRC	2013-23	£1.0M	10
Cardiovascular Science	BHF	2013-20	£0.6M	4
Computational Discovery	UKRI/IBM	2018-22	£1.8M	5

2.2.2 Recruitment and diversity

Recruitment is by interview with cross-departmental panels (for DTPs) or departmental committees and has historically been based largely on a student's academic performance and suitability for research. Self-funded students have to pass this same rigorous selection procedure before they are accepted. Importantly, **our criteria for assessing students have been gradually changing to take more account of equality, diversity and inclusion (EDI)**. For example, the new Wellcome *Chemistry in Cells* programme uses anonymised CVs and incorporates metrics of socio-economic status into its decisions. The University is currently analysing how such metrics can be used most effectively in PGR student assessment, and we will act on any recommendations. We are particularly proud of our support in UOA5 for the *UNIQ+* programme [IES 3.3], which encourages undergraduates from under-represented backgrounds to consider post-graduate study by providing a paid internship and was initiated in MSD and MPLS. We hosted 29 students in UOA5 laboratories in 2019, providing funding, mentoring and guidance on next steps, and were pleased that one of these went on to start a DPhil programme with us. Students may study part-time if they wish to do so.

While there is clearly much room for improvement, our efforts to address EDI issues are leading to progress: in 2019/20, for example, 34% of the new intake of PGR students in the Medical Sciences Division declared BAME ethnicity, compared to 29% in 2013/14.

2.2.3 Quality of student training

The MSD and MPLS Graduate Schools provides thematic training and support for all students within UOA5. Whether entering directly into a department or into a DTP, all students are trained in an **environment in which there is a strong critical mass of experts and resources**.

- **Induction programmes** help integrate students as rapidly as possible and introduce the opportunities available.
- To foster a sense of belonging, a number of **community-wide events are organised**, including a highly successful annual symposium, featuring talks from current students and alumni working in a variety of fields and showcasing a variety of relevant topics. The annual **Divisional DPhil Day** in MSD provides a showcase of graduate student activity across the university.
- Students have access to over 350 courses, including required courses in ethics, plagiarism and good laboratory practice, and all **undergraduate lectures** in the relevant Division.
- A wide-ranging programme of **training in transferable, research and specialist scientific skills** is open to doctoral students, led by a Director of Skills Training and Researcher Development. Over 90 courses and events are offered each year. Recent developments include

new courses in fostering good research practice (research integrity and reproducibility in research).

- The skills programme incorporates specialist **technical courses** available through the Doctoral Training Centres, such as electron microscopy, x-ray crystallography, MATLAB programming and computational biochemistry. Partnership with Diamond Light Source has enabled provision of training direct from Diamond staff.
- Opportunities for **interdisciplinary training and exchange** are fostered. Reciprocal arrangements are in place that provide all students access to courses offered to externally-funded DPhil programmes, such as those supported by Wellcome and the Research Councils.

We have developed our training in translational research and entrepreneurship:

- We work with the University Careers Service to provide **micro-internships** of 2-5 days each giving placements in the private and public sector; interactive workshops developing **commercial awareness** in students; and the opportunity for 1-to-1 careers consultations and to work with Careers Outreach Fellows (individuals who have recently completed a DPhil and can help direct current students towards potential career options).
- Many of our full-funded studentships, e.g. from Wellcome Trust, include a **transitional fund** that can be used to support internships and other activities for career development towards the end of the course.
- Opportunities to **work closely with an industrial partner** are provided by five MRC Industrial Collaborative Awards Studentships (iCASE) per year. Close links with Diamond and pharmaceutical companies provide additional benefits to students through funding support and industry expertise.

We are developing a **course in Innovation Strategy for DPhil Students** with a project team including DPhil student, post-doc, academic, and entrepreneur representation to deliver 50 hours of teaching over an academic year in 2-3 day modules. This builds on recently developed introductory courses in innovation and entrepreneurship.

2.2.4 Support and monitoring

The University is committed to the **QAA *Code of Practice for Research Degree Programmes***, and we support our students and monitor their progress in several ways:

- **All new PGR students are welcomed with a comprehensive induction course**, comprising several lectures and smaller meetings spread over the first 2-3 weeks (on topics such as health and safety and research integrity). These also provide clear guidance on the extensive support and training resources available to students (described briefly at the start of Section 2).
- **All PGR students are appointed an academic advisor or "second supervisor"** within their Department, who provides advice and pastoral support. They meet in the first term and students present a written report about their project, to monitor that they have settled well and are receiving appropriate support. All PGR students are affiliated with a College and assigned a College advisor who provides additional support.
- **Students, supervisors and advisors submit an online assessment of a student's progress every term**, clearly flagging any concerns. All reports are read by the Director of Graduate Studies (DGS), an academic in each Department responsible for that Departments PGR students, and any concerns are followed up with an e-mail discussion or an informal meeting to assess whether further action is required.
- At the end of their first-year **student progress is assessed in a viva** with two independent faculty. If progress is deemed insufficient, the student will meet with the DGS and their supervisor to discuss the extra support required to pass a second viva. Over 95% of students pass this assessment.
- Students are then formally **assessed again at the end of their penultimate year** in a viva, at which they present detailed plans for finishing their work and writing their thesis to two independent faculty. Over 98% of students pass this assessment.
- Of students starting since 2013, **over 90% completing did so within 48 months**.

We support our students' well-being. The University supports a large and well-resourced Counselling Service and in 2019 it published a Student Wellbeing and Mental Health Strategy. In UOA5 it became a formal requirement that every DGS receives in-person training in student mental health, and this requirement is being rolled out to all PGR Supervisors (Section 2.3).

All Departments have a Graduate Student Association (GSA). Like the PDAs, these Associations are given support and autonomy to take on issues and organise events that matter most to their communities, often working across Departments to put on meetings and invite speakers.

Supporting mental health: a supervisor's perspective
"I've been supervising PhD students for more than 20yrs and there has been a dramatic increase in the last few years in the number of students with significant mental health issues, including two cases within my own lab. I've been really impressed by how the Departments and Colleges have supported these students and their supervisors—tailoring help to individual needs, and often bending over backwards to allow them the space and time to work through their issues so they can continue their studies."
***Anonymised UOA5 Supervisor*, *June 2020*.**

2.3 Equality and diversity

Increasing equality and diversity is an important strategic aim (Section 1.2, Aim 2). We are supported by the University's large and expanding EDI infrastructure [IES 3.4], and several UOA5 staff have served on the newly convened Divisional EDI Steering Groups. Much of our work in the current REF period has focused on ensuring that we work in accordance with **Athena SWAN (AS)** Charter principles. All UOA5 Departments have established permanent AS committees that guide policy and monitor progress. Our Departments have three Silver (Biochemistry [until 2023], DPAG [until 2025], and Dunn School [until 2023]) and three Bronze AS awards (Pharmacology, Plant Sciences and Zoology). Pharmacology **will apply for a Silver award in 2021**, while an application for the new Department of Biology must start at Bronze. On gender equality, we are making progress: for example, **29% of our submitted staff in REF2014 were female compared to 37% of our eligible staff for REF2021**.

Importantly, while AS focuses primarily on gender inequality, **we are applying similar principles to other *protected characteristics***

- All Departments have established committees **to support staff with certain protected characteristics** (e.g. disability, LGBTQ+, transgender or those from under-represented minorities), providing a powerful voice for their communities, and driving progress by holding senior leadership to account. For example, many Departments have put in place procedures to formally assess the needs of staff with disabilities, (e.g. leading to the installation of an extra defibrillator within a lab to support a graduate student with a serious cardiac condition); and to upgrade infrastructure for staff and students with audio/visual needs (such as improved access for guide-dogs and audio/visual support systems in lecture theatres).
- **EDI issues are increasingly considered when assigning support.** We seek to give extra support where there are barriers to progress in research and career development. For example, we offer extensive support to all our staff in applying for grants – including, where appropriate, professional support in grant writing (Section 3.1) – but we especially encourage faculty from under-represented groups or those that have caring responsibilities or long-term illness to take up this assistance. We also now closely monitor the success rates of various groups in applying for funding and for promotion, reward and recruitment.

We aim to **provide effective support for part-time staff, and staff with caring responsibilities or health** issues that impact the way they need to work.

- **We support part-time, flexible and/or remote working.** All UOA5 staff can apply to work either part-time, or with flexible hours or to work remotely—and we take the view that these

requests should be granted whenever possible. In 2018, 61% of academic and research staff reported flexible working arrangements and at the census date, 11% worked part-time (headcount).

- **All Departmental seminars and training courses take place in core working hours**, and all essential courses are delivered in house so that all staff can attend.
- **Career progression for part-time researchers.** All part-time staff have access to the same support mechanisms and career opportunities as our full-time staff, and the University has a central team specifically to support part-time workers and students. We work closely with these staff to tailor individual working plans and to ensure that working part-time does not negatively impact career progression.
- **We encourage** staff to take the leave they need due to illness or for personal reasons and to ensure they can keep in touch as will be most helpful.

Supporting part-time staff
"As a postdoc I transitioned from full-time (100%) to part-time (80%) following a 6-month maternity leave (2015). Although keen to return to research, I was conscious of losing an opportunity to spend valuable time with my daughter. Switching to a PT contract was a compromise that benefitted our family enormously, partly because my husband's job often made childcare logistics complicated. I received enormous support from my supervisor and the Department in terms of flexibility during this time. When I started my Royal Society University Research Fellowship (2019), I decided to return to FT work as my daughter had started school. However, I knew that I would have the option to revert to PT if it proved necessary."
Laura Moody,
UOA5 Royal Society URF.

- **We support staff returning to work after periods of leave** with a dedicated University team. These staff routinely have reduced teaching, examining and administrative commitments, and the University's *Returning Carers' Fund* [IES 3.1] provides flexible funding for training, teaching buy-out or small-scale lab equipment; UOA5 staff received a total of £179k from this fund during the current REF period.
- **We have generous maternity and paternity leave policies,** with many Departments adopting specific practices to enhance benefits, providing, for example: (1) 50% relief of teaching during the first year of return from maternity leave to ease the transition back to work; (2) Technical support to allow researchers to effectively communicate with their labs during their maternity/paternity leave if they wish to; (3) "maternity mentors" to support mothers during pregnancy and early motherhood; (4) preferential access to parking spaces for expectant mothers. UOA5 departments have expanded access to affordable child-care facilities [IES 3.1] by sponsoring 19 places in University-run nurseries since 2017.
- **We support staff and students with caring responsibilities/health issues to attend conferences.** Several UOA5 Departments have initiated specific schemes to support this activity, and many UOA5 staff have taken advantage.

Support to attend conferences
*"Scientific research careers can be particularly challenging for women, especially when they become mothers. When my daughter was born I was invited to join the Athena SWAN Committee and I suggested they set up a support scheme to provide a **childcare allowance** for periods spent away at speaking engagements or conferences, which you have to do if you want to raise your profile. They agreed to establish a **Departmental Carers Fund**, which has been used, and much appreciated, by many female researchers."*
Monika Gullerova, UOA5 PI.

We recognise the pressures that current research and working practices can sometimes put on staff and students, and **we support the well-being of all our staff and students**.

- We supported several **staff initiatives to promote wellbeing**, providing practical (and in some cases financial) help. For example, classes in yoga, pilates and general fitness have been organised by Departmental student or post-doc associations, and are all well attended.
- **We have improved communication,** including regular monthly (weekly during parts of the COVID-19 crisis) Newsletters from our HoDs, and upgrades to our intranet services to allow easy communication between various groups of staff. These upgrades have supported several well-being initiatives—ensuring, for example, that all staff have easy and reliable access to the complex and rapidly changing guidelines and instructions on safety and working practices during the COVID-19 crisis, and know the support available to them.

Supporting staff during the COVID-19 crisis

"First, working from home for some people is difficult. Your productivity may not be as high as you want it to be. For some, especially those with kids or other caring responsibilities, it may be close to zero. That's OK. Focus on the important things.
Second, for those of us who are able to work from home, it is likely that our kitchen tables, spare bedrooms, sofas etc, are not as ergonomically efficient as where we normally work. If you have a justified need for any minor equipment, the department will cover a reasonable cost ....
Finally, mental health is equally important and, again, there are resources on the intranet pages. Our mental health first aider, our bullying and harassment advisers, and the student welfare team, are always available if you need support."

HoD, Dunn School of Pathology, Staff Newsletter, *April 2020*.
Edited lightly to remove personal information.

2.3.1 Equality and Diversity in our REF submission

We have strived for equality and diversity in our selection of outputs for REF2021 [IES 3.4]. We invited all researchers to nominate one or more outputs for consideration, making it clear that they should include all to which they had contributed significantly. Every output was internally reviewed by at least two people and scores were then moderated by groups of three senior academics, with one senior academic present at all meetings to ensure consistency. All scores and comments were recorded, and decisions documented, in a central and secure database.

Eligible outputs were then selected based on their score and attributed to individual authors initially using an anonymised dataset to encourage allocation of each output to any individual who had made a sufficient contribution, regardless of seniority or other bias. We performed an equality impact assessment on a provisional selection of outputs, conducted centrally by the University to ensure limited access to sensitive data. This helped confirm principles for the final selection of outputs. We strictly respected the commitment of our Code of Practice that this data was not made available for any other purpose.

3. Income, infrastructure and facilities

3.1 Income

Enabling our researchers to obtain significant amounts of external funding, through strategies described below, helps maintain a critical mass of outstanding researchers in our Research Groups and grow those areas with greatest potential.

These strategies have been successful, and a comparison to REF2014 reveals that our average income per year from all sources [REF4b] has increased significantly. Most notably, *average annual funding* from **UK Research Councils increased by 16%** (from £15.8M to £18.4M/yr); from **UK Charities by 40%** (£24M to £33.6M/yr); from **EU Government by 55%** (£5M to £7.7M/yr, primarily the EC); and from **UK Industry by >300%** (£0.58M to £1.99M/yr).

Research income reported for 2015/16 in REF4b includes £43.9M capital income that was incurred in other years but, due to a change in HESA reporting conventions, could not be aligned with the expenditure date.

Much of this income supports individual research faculty at project grant level (grants of ~£0.2-£0.6M for 2-3yrs), but our researchers also secure programme level support (typically grants of £1.5M-£2.5M for 5yrs), mainly from Wellcome (6 PRFs, 11 SRFs and 16 Senior Investigators), but also from BHF, CRUK, UKRI and ERC. Of research awards that started during the REF period, more than half (by value) were for 5 years or longer. Other fellowships commenced during the REF period include 8 Sir Henry Dale and 6 Sir Henry Wellcome Fellowships from the Wellcome Trust; 5 Royal Society URFs; 4 MRC Career Development awards; 3 BBSRC Discovery fellowships; and 33 EC Marie Curie Fellowships.

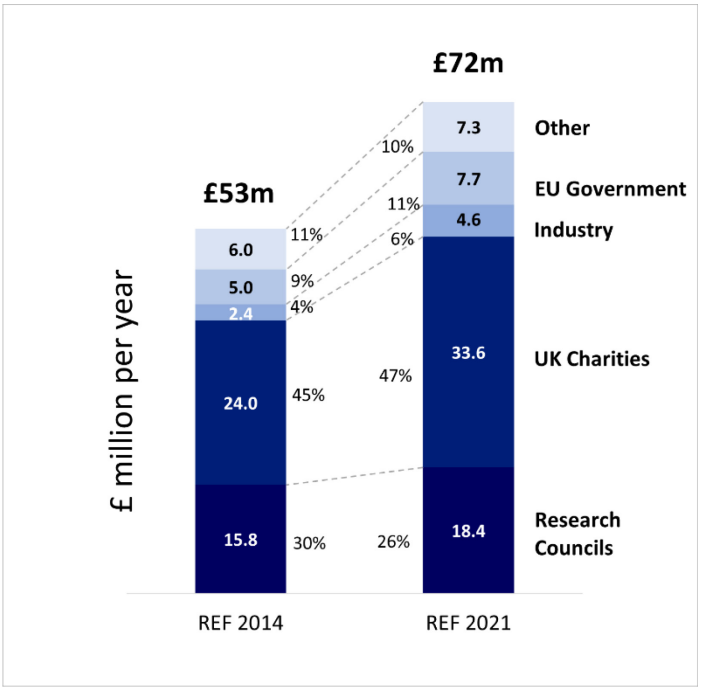


Figure 3
Average annual research income over periods of REF2014 (2008-13) and REF2021 (2013-20). Industry sources include UK, EU and non-EU. [REF4b]

We encourage our researchers to apply for larger research grants in collaboration with scientists from other UOAs or Institutions, e.g. 10 Wellcome Strategic and 6 Collaborative, 3 BBSRC Strategic 'Longer and Larger' (sLoLa) and 11 H2020 collaborative awards together brought in excess of £11M income. For example, Novak led a BBSRC sLoLa on systems-level characterization of mammalian cell cycle transitions (2014-2020, £3M) with collaborators at the University of Sussex and the Institute of Cancer Research; and Langdale's 2019 award from the Gates Foundation to study C_4 rice has

collaborators in Cambridge, Germany, Australia, Taiwan and the USA (total funding $13.1M, £3.6M to Oxford).

We have long-term strategic relationships with our major funders (UKRI, Wellcome, BHF and CRUK), guiding us to deliver research better aligned with their stated priorities and objectives. Our concentration of research activity in their remit has underpinned investment in strategic research Centres, such as the *CRUK Oxford Centre* and the *BHF Centre of Research Excellence*. These Centres receive significant core support across multiple UOAs that enhances our research environment by funding studentships, providing pump-prime funding, and supporting facilities (Section 4.1). The *Centre for Neural Circuits and Behaviour* (CNCB) renewed core funding from Wellcome (£3.6M) enabling seminal discoveries in sleep, memory extinction and behavioural decision making in flies (e.g. Felsenberg et al., *Nature*, 2017; Groschner et al., *Cell*, 2018). Our income from the European Commission (~£47M) also supports several projects that are part of major international collaborations, such as the stem cells for drug discovery (*stemBANCC*) initiative (Akerman, James, Wade-Martins, Weber).

Our Wellcome Trust *Institutional Strategic Support Fund* (ISSF) is managed internally across streams including early-career pump-priming and strategic initiatives and total of £1.68M supported 52 projects in UOA5 during the REF period. Our MRC *Confidence in Concept* award supported 29 translational projects, with income £573k, with £72k from the MRC Pathway to Discovery scheme for relationship-building.

The most dramatic growth in our funding comes from UK industry. Although this remains relatively small (~£14M total) the increase reflects the effectiveness of support from our Divisional Translational Research Office and Business Partnership teams. For example, UOA5 investigators received >£1M for translational research projects through *OSI/Lab282* and >£9M in research grants from companies such **AstraZeneca**, **Roche**, and **Syngenta**.

An important element of our strategy has been to secure substantial **philanthropic funding**. Our successes include, for example, securing major donations to support research in our new buildings (Section 3.2). In response to the rapidly emerging COVID-19 crisis, we used unrestricted philanthropic donations received for COVID-19 research to establish a new fund to support high quality, high impact projects. 256 applications were received and reviewed, through 4 rounds over the course of 11 weeks during April – June 2020. 91 awards have been made across the University to projects totalling £8.2M, of which 10 awards totalling £497k were led by UOA5 researchers.

We also benefit from **research income in-kind** (Table REF4c), allowing our researchers to make use of **shared research infrastructure located in other HEIs or facilities**—e.g. through awards of synchrotron beamtime at Diamond (£4.4M total) and the ESRF (£1M) and for time at the ISIS neutron source (£1.7M). UOA5 researchers have also been awarded time at the Central Laser Facility, High Field NMR, the ILL neutron source and the NERC Biomolecular Analysis Facility. These resources have supported transformational work, particularly in our Structural Biology, Biophysics and Computational Biology Group—e.g. explaining the molecular basis of pH-dependent ER retrieval (Brauer et al., *Science*, 2019), sugar transport into the Golgi (Parker and Newstead, *Nature*, 2017), GPCR regulation by PIP2 (Yen et al., *Nature*, 2018), and the function of secretion systems used by pathogenic bacteria (Lauber et al., *Nature*, 2018).

In addition to central provision to support research grants and contracts [IES-4.1], we have also strengthened local support to help our staff formulate projects and obtain funding. For example, we provide extensive support for grant writing, arranging meetings with senior staff at an early stage to discuss grant strategy, subsequent comments on proposals and, where relevant, mock interviews. Several UOA5 Departments now have professional leads coordinating these activities. Increasingly, and to meet our EDI goals, **this support is targeted** at staff who need the most support overcoming barriers to success (e.g. junior faculty, under-represented minorities, staff with caring responsibilities).

3.2 Facility infrastructure to support research and impact

As described in Section 1.2, Aim 1, an important strategy is to support research and impact by investing in facilities that provide **specialist research infrastructure**; once established, these facilities are expected to run on full-cost-recovery models. These facilities ensure that our researchers have access to state-of-the-art technologies supported by expert technical staff. These facilities act as interdisciplinary hubs for sharing expertise and coordinating activity across Departments and disciplines (e.g. to assess user needs and to leverage additional funding). In addition, we expect them to **stimulate collaborations and exchange** with both **academic researchers** and with **industrial partners to promote impact**. Here, and throughout Section 3, we focus first on one example (advanced bioimaging) to illustrate how our facilities generate impact and contribute to the research environment locally, nationally and internationally. We then more briefly describe other facilities that take similar approaches.

3.2.1 The Micron Advanced Imaging Consortium (Micron)

Microscopy is a crucial tool in many areas of biology, and there are an increasing number of sophisticated modalities that are expensive to acquire and technically challenging to use. **Micron** was established in 2012 to address these needs with a Strategic Award from Wellcome, which was enhanced in 2016 (~£4.7M from Wellcome, ~£1.5M from Oxford). This new award funded several facility microscopes and established an interdisciplinary team to design and build advanced imaging systems.

In the Micron model, technical support staff and/or equipment are located at multiple sites across Oxford, within four of the UOA5 Departments; molecular medicine, human genetics and rheumatology units within clinical medicine (all UOA1); Engineering (UOA12); and Chemistry (UOA8). These separate sites are financially independent of each other, but their activities are coordinated within the Micron umbrella. A strategy meeting (open to all) is held every month to discuss best practice and to coordinate equipment needs and purchasing strategy. An important operating principle is that all Micron equipment, no matter where located, is equally accessible, and at the same cost, to all academic users (both inside and outside the University). These principles promote the efficient use and sharing of equipment and technical expertise. At the central Micron sites (in Biochemistry and the DS), for example, there are >400 registered facility users, and **>50% of these are from outside their respective Departments**. Micron facilities are also used by ~10 industrial partners, who pay higher access charges—contributing to the long-term sustainability of Micron—and who benefit from Micron's expertise and large user-base to test and give feedback on their new technologies (e.g. Oxford NanoImager [ONI], see below).

This coordinated strategy has allowed the Wellcome grant to be effectively leveraged to secure significant additional funding, most notably from the MRC (>£2M) and the University (>£2M). For example, the University hired a new Micron PI (Schermelleh) to enhance technology development and ensure ease of use for biologists. Schermelleh has guided collaborative advanced imaging projects with several groups in Oxford – e.g. on the mechanisms of X-chromosome inactivation (Almeida et al., *Science*, 2017) – and elsewhere – e.g. a collaboration with researchers in Denmark and The Netherlands on chromosome topology and genome integrity (Ochs et al., *Nature*, 2019).

The concentration of advanced technology and technical expertise in the facility has stimulated several academic and industrial collaborations. For example, Micron part-funded the development of a TIRF-SIM system at Oxford's Kennedy Institute of Rheumatology (with Fritzche, UOA1), leading to a partnership with the Rosalind Franklin Institute to develop the Biophotonic Correlative Optical Platform. The collaboration with Fritzche led to the inclusion of the Zeiss Centre of Excellence in the IDRM (with Riley and Srinivas [UOA5]), and the Micron Zeiss Lattice Light Sheet system currently in Biochemistry will relocate to this centre. Micron also worked extensively with Oxford NanoImager (ONI) to develop their first prototypes, benefitting both the company and also the facility, through enhanced access to new technologies and technical support. Micron facilities are also used by researchers from other Universities, generating further academic collaborations (e.g. Exeter, Nottingham, Southampton, Warwick).

We also expect our facilities to take an active role in training our researchers, and Micron organises two annual week-long advanced microscopy courses for staff (including many from other UOAs) on the central Oxford site (~70 attendees), and at the JR hospital site (~30 attendees). Both courses are popular and are always oversubscribed.

3.2.2 Cryo-EM (COSMIC)

Technical advances in cryogenic electron microscopy (Cryo-EM) are revolutionising structural biology, and establishing communal facilities for the biological sciences in central Oxford was recognised as an urgent priority in 2015. The Central Oxford Structural Microscopy and Imaging Centre (COSMIC) was established by UOA5 researchers in 2017 with grants from Wellcome (£2.1M), The Royal Society/Wolfson (£1M) and the University (£1.1M). The facility houses several Cryo-TEM systems (e.g. FEI Talos, Arctica and Titan Krios systems) and has been central to several successful large grant applications (e.g. Higgins, Lea and Newstead's individual Wellcome Investigator Awards), and has facilitated several outstanding recruitments (e.g. Bharat and Elliot), and ground-breaking discoveries (e.g. on the structure of the bacterial surface layer [von Kügelgen et al., *Cell*, 2020; Tarafder et al., *PNAS*, 2020] and the bacterial flagellum [Deme et al., *Nat. Micro.*, 2020]).

3.2.3 James Martin Stem Cell Facility

Established by UOA5 researchers in the previous REF period, this Facility trains researchers to work with human induced Pluripotent Stem Cells (iPSCs), running annual workshops for researchers across the UK and worldwide. The Facility has pioneered methodologies for the efficient differentiation of primitive macrophages and microglia. These are in high demand for modelling innate immunity, host-pathogen interactions and neuroinflammation and the Facility has established several industrial collaborations (e.g. Roche, Eli Lilly) and is an important partner in several national and international academic programmes (e.g. the *MRC Dementias Platform* and *EU IMI StemBANCC*).

3.2.4 The Advanced Proteomics Facility (APF)

The APF was established in 2016 by the merger of the proteomics facilities in the Department of Biochemistry and DS, with a world leader in proteomics development to lead the Facility, jointly appointed with Chemistry (Mohammed, UOA8). The APF provides proteomics services and training to >50 groups across Oxford and has supported several important discoveries—e.g. on the molecular details of mitotic exit (Holder et al., *eLife*, 2020) B Cell senescence (Zhang et al., *Mol. Cell*, 2019) and viral infection (Garcia-Moreno et al., *Mol. Cell*, 2019).

3.2.5 Genome Editing (GEO)

The Genome Engineering Oxford (GEO) research facility is a cross-Departmental UOA5 venture established in 2014 with internal funding (~£150K). It provides a range of genome engineering services as well as extensive advice and training to our researchers (currently working with ~50 groups in Oxford). GEO is involved in several large-scale collaborative projects, e.g. Hassan (UOA5) and Doench (Broad Institute, USA) using genome-wide CRISPR screens to establish synthetic lethality relationships in cancer cells.

3.2.6 Next Generation Genomic Technologies

In 2014, an internal analysis revealed a dramatic increase in the number of UOA5 groups using functional genomic approaches. It identified data turnaround times as a significant bottleneck, so we secured internal funding (~£400k) to establish a cross-Departmental Next Generation sequencing and genomics facility. This allowed researchers to acquire data in <72 hrs (compared to a minimum of 2 weeks [mean >4 weeks] at the remote facilities used previously). More than 40 research groups use the facility, and it has supported several important discoveries—e.g. how dsRNA triggers anti-viral responses (Dhir et al., *Nature*, 2018) and how transcription is coupled to RNA processing (Nojima et al., *Cell*, 2015).

3.2.7 The Molecular Biophysics Suite (MBS)

The MBS was established in 2007 as a protein characterization facility comprising twelve core pieces of biophysical equipment (e.g. SPR, ITC, CD, AUC, SEC-MALS). There has been ~£500k of investment in new equipment during the current REF period. The facility provides services to numerous Oxford spin-outs and biotech companies and supports >30 research groups, facilitating numerous important molecular insights—e.g. how Plasmodia evade immune detection (Harrison et al., *Nature*, 2020), and how mitotic centrosomes assemble (Feng et al., *Cell*, 2020).

3.3 Organisational infrastructure to support research and impact

During this REF period we have made a considerable investment of time and effort to plan, and secure funding for, three major new buildings that will help to ensure the long-term sustainability of the biological sciences in Oxford. We also invested £4.5M in a substantial refurbishment of the Sherrington Building for improved laboratory space and infrastructure. Here we briefly describe the context, benefits and opportunities the new buildings will provide.

3.3.1 The Life and Mind Building

The Tinbergen Building (home to the Department of Zoology and Department of Experimental Psychology (UOA4)) was unexpectedly forced to close in 2017 due to the discovery of asbestos [IES 2.1]. The building housed ~380 Zoology researchers and important infrastructure such as the central Genomics Facility. The closure necessitated a complex logistical operation to quickly move the displaced Department (mostly to nearby UOA5 Departments), and then to move staff and facilities again into new medium-term, purpose-designed modular laboratories (£16M) assembled on a nearby cricket pitch. We also provided support to staff and students by underwriting all graduate scholarships and fixed-term research positions that were impacted by the closure. All experimental research was back up and running within 15 months of the initial closure.

We then committed a further £202M to the construction of a 25,000m^2 building, to open in 2024. This is currently the largest capital project the University has ever undertaken. The building will house the new unified Department of Biology (Section 1.2) and the Department of Experimental Psychology (UOA4). **The LaMB will provide exciting opportunities to strengthen and support interdisciplinary research**, providing physical space to host and expand interdisciplinary hubs that draw in researchers from biological disciplines across Oxford. From 2021, for example, these efforts will be boosted by the creation of approximately 80 new research posts across the Biology & Chemistry (UOA8) departments to drive work on the development of new antibiotics for human and agricultural use, and to develop evolutionarily-inspired solutions to the challenge of anti-microbial resistance in a new Centre, to which INEOS have committed a gift of £100M [IES 2.1].

3.3.2 Dorothy Crowfoot Hodgkin Institute (DCHI)

If the second half of the 20th century was the age of molecular biology, then the first half of the 21st century is rapidly becoming the age of the cell. The DCHI is a core strategic initiative to meet this challenge. This interdisciplinary institute will bring together biologists from UOA5 with chemists, physicists, engineers, and computational scientists, emphasising the interface between the life and physical sciences, and laying the foundations for future biomedical discoveries. The building for the DCHI (£92M) will serve as a hub on the central campus (Figure 2) to facilitate cross-departmental and cross-divisional collaboration. Senior leadership will come from Freeman (UOA5), Robinson (UOA8) and Kapanidis (UOA9). The building will house 550 staff (approximately one third from UOA5, including several current staff from Biochemistry, DPAG and DS). The new space will allow us to hire new research staff to strengthen interdisciplinary approaches, and Statutory Chair vacancies (e.g. Chemical Pathology, Molecular Microbiology) will allow us to bring in new leadership in strategic areas. The recent **philanthropic donation of $10M from the Kavli Foundation** will support the ***Kavli Institute for NanoScience Discovery*** within the building and the Krebs Chair in Physiological Metabolism. The building project is on schedule for completion in late 2021.

3.3.3 The Institute of Developmental and Regenerative Medicine (IDRM)

Two thirds of all deaths world-wide (pre-COVID-19) are due to non-communicable diseases, and there is an urgent need for the development of new drugs and therapeutic strategies to replace and restore damaged tissues. The IDRM is the first research institute in the world to physically merge the disciplines of developmental biology and regenerative medicine, and is a timely collaboration between researchers in UOA5 and Clinical Medicine (UOA1). Under the leadership of Riley (UOA5) the IDRM will bring together ~220 researchers with a focus on developing novel tissue engineering applications for regenerative medicine and AI and mathematical approaches to enhancing in-house drug discovery programmes. The £32.5M building is located on the Old Road Medical Campus, accessible from UOA5 Departments and our clinical collaborators (UOA1) at the Churchill and JR hospital sites. **Substantial (>£8M) philanthropic funding** has been secured to endow a Chair, support several DPhil studentships and support -omics and bioinformatics infrastructure linked to the nearby Big Data Institute (BDI). The Institute will also partner with the nearby Kennedy Research Institute (KRI) to establish the Zeiss Centre of Excellence for state of the art confocal and light-sheet microscopy.

3.4 Other support for research and impact

3.4.1 Gardens, Libraries and Museums

Many of our researchers make extensive use of the **unique facilities and research collections** available through the University's **Gardens, Libraries and Museums (GLAM)**, and the Director (Hiscock) and the Deputy Director (Thorogood) of the Botanic Garden & Arboretum are independent researchers in UOA5. Our departments also benefit from close physical proximity to GLAM's venues, which provide important opportunities for public engagement with research through the ~3.2M visitors they attract every year (examples in Section 4.4).

3.4.2 Investment in IT Infrastructure

Although each UOA5 Department has its own IT support facilities we have worked closely during the current REF period to improve and better coordinate our IT infrastructure. This has included improving the connectivity between Departments (which is essential, for example, for the efficient transfer of data from our communal research facilities), and significant upgrades to our data storage and computational power (which is essential for our Cryo-EM, image analysis, Omics and computational simulations work). Several major grants included funding for upgrading this infrastructure, including an Oxfordshire Local Enterprise Partnership (OxLEP) research infrastructure award (Dolan, Kelly, Mackay; ~£0.45M).

3.4.3 Research support staff

World-class research requires world-class technical and administrative support, and we aim to employ an appropriate number of talented and dedicated staff in these roles. We have implemented many of the practices described in Section 2 (such as inductions for new staff, improved mentoring) for this category of staff, and they also have access to all the support and training infrastructure that are available to our research staff. The University is a signatory to the UK-wide **Technician Commitment** to support career development of technical staff, and we have developed an action plan to provide better training and recognition. We also support an extensive Apprenticeship scheme, providing exciting, and often life-changing, opportunities for apprentices of all ages to train alongside experienced staff to develop their professional skills whilst growing the University's pool of talent. Nine apprentices worked in UOA5 Departments in July 2020.

3.5 Equality and diversity in accessing support and facilities

We have adopted several practices and strategies to ensure that equality and diversity principles apply to the ways in which we support our staff to apply for grant income. For example, we target grant-writing support to staff who are from under-represented minorities or who have caring responsibilities (Section 3.1), and we have recently identified the problem of gender and ethnic

imbalance in the proportion of our staff involved in commercial activity, and are actively seeking to address this (Section 1.5).

An important element of our inclusion strategy is to ensure that all our researchers have equitable access to our facilities. For example, we realised that smaller Groups, which are more likely to be run by junior faculty or part-time staff, may be prevented from using the most appropriate or sophisticated equipment simply because they have less overall funding than others. In Micron, for example, we therefore operate a 'sliding cap' charging system, where annual facility charges are capped at a lower rate for smaller Groups. It was also recently brought to our attention through an Athena SWAN committee that several staff with caring duties were not getting sufficient time on some of our most popular microscope systems because they were so heavily booked during core working hours. A trial was initiated to give these users preferential booking rights on certain days of the week. It proved challenging to get this system right but, after several iterations, practices have been established that address the needs of all users.

3.6 Shared use of research infrastructure

We plan for much of our research infrastructure to be shared with other HEIs and that our scientists will use shared infrastructure elsewhere. As our most extensive and distributed bioimaging facility, Micron is again an exemplar.

Micron collaborated with Oxford Brookes University in 2014 to establish a joint centre for Serial Block Face Imaging EM (based at Oxford Brookes) with BBSRC funding (~£0.8M; Raff [UOA5], Hawes and Vaughan [Brookes]). This facility has been used by researchers at several other HEIs nationally (e.g. **Dundee, York, London**) and internationally (e.g. **Germany, France, Portugal, Spain, Czech Republic, The Netherlands**) enabling important collaborative discoveries, e.g. on mitochondrial genome segregation (Hoffman et al., *PNAS*, 2018) and plant growth (Kleine-Vehn et al., *PNAS*, 2016). Micron helped build the first super-resolution 3D-Cryo-SIM system to be incorporated into an X-Ray beamline at Diamond (Kounatidis et al., *Cell*, 2020). Although only recently becoming operational, 24 proposals to use the system have already been accepted (after peer review) and only five of these are from within Oxford—the others from **the UK, Europe and Japan**. Micron has established close relationships with several HEIs overseas, e.g. four of our researchers individually spent several weeks at the **HHMI Janelia Research Campus (USA)** to learn how to use various high-end microscopes. In one case this led to our building our own TIRF-SIM system in Oxford (Section 3.3.1). Many of our other research facilities engage in shared projects with other HEIs, and some additional examples are described in Section 3.3.

3.7 Benefits in kind

Due to our size and the breadth of our research we are often in a position to secure benefits-in-kind. As just one example, many microscope companies want to place their new systems with us, as our knowledge about the system spreads rapidly through the bioimaging community. In several instances we have negotiated several years of free service contracts on our systems on the understanding that we will provide feedback on performance and allow the supplier to bring potential clients to Oxford to see the system and talk to our users. This has the added benefit that our systems are well-maintained and are frequently updated free of charge. During the Covid-19 crisis, Micron was able to leverage its relationship with both Olympus and Oxford NanoImager (ONI) to temporarily loan versions of their latest instruments, free of charge, to conduct innovative microscopy-based COVID-19 research in Micron and also with collaborators at the JR hospital (see Section 4.8).

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

4.1 Research collaborations, networks and partnerships

Our environment is structured to be flexible and to **nurture the exchange of ideas and resources amongst our researchers and across disciplines**. We encourage such collaborations in several ways, including by organising and supporting themed networks (often across Research Groups and UOAs), and by providing rapid access to seed-funding to support interdisciplinary collaborations and to generate initial data that can be used to leverage external funding. 14% of the funded research projects contributing to our research income [REF4b] had collaborators within the University but in another UOA (most commonly UOA1, Clinical Medicine).

For example, the **CRUK Oxford Centre** is supported by a core grant from CRUK (~£2M/yr) and comprises 258 research groups. It holds an annual Oxford-wide meeting, provides pump-priming targeted at interdisciplinary collaborations between clinicians and researchers and it funds a cohort of ~11 research students per year in a mix of clinical and basic research labs. Funding from the Centre, for example, was instrumental in facilitating the collaboration between Wilson and Goberdhan (UOA5) and Hamdy (UOA1) to explore the *Drosophila* accessory gland as a model for prostate cancer (Leiblich et al., *PLoS Biol.*, 2019; Wilson et al., *Curr. Top. Dev. Biol.*, 2017).

Similarly, the **BHF Centre of Research Excellence (CRE)** brings together ~80 PIs studying cardiovascular biology and disease. It coordinates four major interdisciplinary Themes – Genomics, Population Science, Target Discovery and Development & Regeneration (working closely with the BHF Centre for Regenerative Medicine, synergising with the new **IDRM**). The Centre supports a transitional fellowship programme, which supports promising junior faculty for 2 years so they can develop their independent research programme in preparation for applications for external funding. CRE Fellows Sparrow and Stone, for example, were awarded a BHF Senior Fellowship (£0.94M, to study heart disease) and a Wellcome Henry Dale Fellowship (£1.3M, to study heart development in zebrafish), respectively.

During the REF period the **Oxford Immunology** (276 PIs, 40 in UOA5) and **Oxford Metabolic Health** (60 PIs, 14 in UOA5) networks were established across MSD and MPLS, and both include UOA5 researchers in their cross-disciplinary communities. Oxford Immunology was essential in coordinating parts of our rapid response to COVID-19. The networks each have a research facilitator to enable communication, collaboration, manage pump-priming funds and organise events. UOA5 involvement spans structural and computational immunology, infection, vaccines (ICS-20FLU) and metabolic processes.

We also encourage our scientists to collaborate more broadly with scientists in the UK and abroad. 63% of papers published by our submitted researchers during the REF period had co-authors outside the UK and a further 15% had UK collaborators beyond Oxford (SciVal, Jan 2021). Some of the major collaborations we have supported were highlighted in the description of our Research Groups (Section 1.3) We encourage external interaction, in part, by organising themed groups and meetings and by encouraging our **research facilities** to drive collaborations with external scientists and research bodies. Some examples of wider collaborations initiated in the current REF period are described below.

- The Oxford Parkinson's Disease Centre (OPDC) forged links with several external neurodegenerative disease consortia and Wade-Martins heads a major **EU StemBANCC (a €50M EU IMI Consortium)** work-package to use stem cells for drug discovery in this area. He also leads the **Dementias Platform UK Stem Cell Network**, an £8M collaborative programme (involving seven UK Universities, AZ and GSK) to exploit iPSCs for dementia research. These collaborations have generated important insights into the fundamental pathology of neurological diseases—e.g. tracking the movement of dopaminergic neurons

(Dodson et al., *PNAS*, 2016), and the underlying mechanisms of their loss in disease (Benkert et al., *Nat. Comm.*, 2020).

- **The Livestock, Environment and People (LEAP)** initiative was initially established by researchers in UOA5 (Godfray) and UOA2 (Jebb) who organised a series of conferences in Oxford to explore the health and environmental impact of global animal food consumption. It is now a global research partnership with the *International Food Policy Research Institute*, *The Nature Conservancy* and the supermarket *Sainsbury's* with research funding (~£5.5M in total) from the Oxford Martin School, Wellcome and the EAT-Lancet Commission on Food, Planet and Health. This collaboration has led to several important publications, most recently on methods for managing nitrogen to restore water quality in China (Yu et al., *Nature*, 2019).

- The Oxford Rare Diseases Initiative (Davies, Wood, Platt, Robins) brings together ~250 Oxford scientists working on rare diseases that affect ~350 million people globally. This consortium led to the establishment in 2019 of the **Oxford-Harrington Rare Disease Centre**, a formal partnership with University Hospitals in Cleveland (USA) with a mission to combine the two Centres' strengths to deliver new treatments for rare diseases.

- Our broad strength in evolutionary biology, biodiversity and genomics led to our researchers (Holland, Lewis and Richards) becoming major investigators in the Wellcome funded **Darwin Tree of Life Project** (£9.4M), a collaboration involving several partners—e.g. *Edinburgh*, *EMBL*, *The Natural History Museum*, and *Royal Botanic Gardens*—utilising the facilities at the Sanger Centre (*Cambridge*) to sequence the genomes of all 60,000 eukaryotic organisms in the UK and Ireland. The upgrading of our facilities at Wytham Wood (Section 1.3, Group 9) was central to this project.

- The **Micron facility** collaborated with Diamond to build the first Cryo-SIM system on an X-Ray beamline (Kounatidis et al., *Cell*, 2020) and with Yale, EMBL and Cambridge to produce a 4pi super-resolution microscope incorporating adaptive optics, six of which have now been installed in labs worldwide. Micron is an active member of the UK Bioimaging network and is a founder of the European Super-Resolution Developers Network, involving researchers from over 30 European institutions. The **COSMIC Facility** initiated a collaboration with Monash University (Australia) to develop revolutionary computational methods that allow the online, real-time, processing of CryoEM data (Ceasar et al., *J. Struct. Biol.*, 2020). The team have so far organised five workshops, training more than 300 researchers worldwide. Our **MBS Facility** is a founding member of the international ARBRE-MOBIEU network of biophysical facilities that provides crucial benchmarking of new biophysical techniques.

4.2 Interactions with research users and beneficiaries

One of the ways in which we aim to maximise the impact of our research is by establishing effective relationships with key users and beneficiaries. We do this, in part, by providing an extensive support infrastructure to help our scientists engage with commercial and public bodies through, for example, our Business Partnerships Office, our Translational Research Office and the Oxford Policy Engagement Network (OPEN) (Sections 1.2 and 1.5). Through such interactions many of our scientists are actively engaged with various public bodies (Section 4.3.2). 6.7% of all papers published by our submitted researchers had co-authors from a commercial laboratory (SciVal, Jan 2021).

In addition, **we expect our research facilities** to act as technology hubs to drive such interactions, and many have done so. For example: (1) building on their relationship with **Micron**, ***Zeiss*** are now partnering with the **IDRM** to establish a Centre of Excellence to test their newest equipment and to fund DPhil students to work on microscope development; (2) the **James Martin Stem Cell Facility** has formed partnerships with ***Roche, Eli Lilly*** and ***Janssen*** to establish patient-derived cell-lines to help tackle disease using the facilities human iPSC technologies and expertise; (3) **the Molecular Biophysics Suite (MBS)** collaborates with several commercial partners on instrument development (e.g. ***Red Shift Bio*** on IR spectroscopy and ***Malvern Panalytical*** on Differential Scanning

Calorimetry). All these interactions impact the economy (by leveraging our research expertise to generate commercial benefits) and also enrich our research environment (providing our scientists with enhanced access to new research technologies and reagents).

4.3 Wider contributions to the economy and society

4.3.1 Contributions of our Spin-out Companies.

One direct way that academics can contribute to the economy and society is by **commercialising their work**: this supports jobs and economic activity, and the companies can generate outcomes that are beneficial to society. Here, we summarise the activity of some of the twelve companies spun-out of UOA5 during the current REF period that are not in our Impact Case Studies. Several illustrate the frequency of our collaborations across disciplines and UOAs.

- **Evox Therapeutics.** Founded in 2016 by El-Andaloussi, Lundin (both UOA5) and Wood (UOA1, genetics), the company develops extracellular vesicle-based therapeutics. It raised £10M from OSI and then £46M from US investors. In 2020 Evox announced major partnerships with Takeda and Lilly, worth up to $0.8 billion and $1.2 billion in upfront, development, and commercial milestone payments, respectively. The company employs ~95 people at the Oxford Science Park, with their first phase I clinical trial scheduled for 2021.
- **SpyBiotech.** Founded in 2017 by Howarth with Draper, Biswas and Jin (UOA1), the company harnesses a novel technology for protein assembly to transform the speed and efficacy of vaccine production. The company has raised >£10M and employs 9 people. It is currently conducting phase I/II clinical trials for a SARS-CoV-2 vaccine and is preparing to enter phase I trials for cytomegalovirus (CMV), a major cause of deafness and blindness.
- **Circadian Therapeutics.** Founded in 2016 by Vasudevan (UOA5), Foster and Jagannath (UOA4), the company exploits the identification by Vasudevan of potent modulators of circadian rhythms to potentially treat patients suffering from certain sleeping disorders. The company raised £7.5M and is conducting a Phase Ib trial in partnership with the Blind Veterans UK charity, a collaboration already generating benefits for patients and carers (Section 4.3.3).
- **Pepgen.** Founded in 2018 by Godfrey, Wood (UOA1, genetics) and Gait (Cambridge), Pepgen develops peptide entities for delivery of therapeutic oligonucleotides targeting neuromuscular diseases. It raised £5M from OSI, and then a further £37M to support development of two lead clinical programs for Duchenne muscular dystrophy and myotonic dystrophy type I—the first of which is expecting clinical trial authorisation in 2022. The company is currently based in the *BioEscalator*, and employs 10 people.
- **iotaSciences.** Founded in 2016 by Cook, Feuerborn (UOA5) and Walsh (UOA12) who realised that because gravity becomes irrelevant at the microscale (e.g. raindrops on window panes), the solid surfaces in conventional microfluidic chambers could be replaced by fluid walls made with an immiscible liquid. The company has raised £9M and employs 17 people.

Setting up a spin-out company
"*I came to Oxford as a post-doc to work on transcriptional regulation. After a chance meeting in College between my PI and a Professor from Engineering I started working on an approach to merge drops in tubes and to transfer material between them. We realised that these techniques offered a unique and massively simplified approach to derive microfluidic architectures that had many benefits over existing technologies.*
Setting up a company to exploit our research was pretty complicated, especially for novices like us, so the infrastructure and support that OUI and OSI provided was crucial. I particularly liked how they arranged meetings with other companies that were at similar stages. These discussions gave me the confidence that we were doing the right things."
Alex Feuerborn,
Chief Scientific Officer, *iotaSciences*.

- **Animal Dynamics.** Founded in 2015 by Thomas, the company exploits his research in Evolutionary Biomechanics, with initial projects including the *Skeeter* flapping winged dragonfly-drone based on the understanding of insect flight aerodynamics, stability and control. The company has raised £19M and has 60 employees.
- **MOA Technology.** Founded by Dolan in 2017 to develop next generation herbicides. Like antibiotics, the over-use of herbicides has led to the emergence of epidemic-levels of herbicide-resistance that threaten global agriculture. Dolan developed technology to discover new herbicides and identify their targets. The company is located in the *BioEscalator* and has raised $16M. Field trials with their first herbicides began in 2020.
- **Zegami.** Founded in 2016 by Taylor and Noble, Zegami is an AI enabled image analysis platform for high throughput imaging and visualisation. The company raised £6.5M and employs 15 people, focused on biomedical imaging and several applications including agriculture, human resource management and sports analytics.

4.3.2 Contributions to public health and policy

Many of our researchers are leaders in their field and so contribute to the economy and to society by sitting on panels that **advise governments and NGOs.** Prominent examples include: McLean (*Chief Scientific Advisor to the MoD*); Godfray (*Chair, DEFRA Science Advisory Council*); Macdonald (*Chair, Natural England's Science Advisory Committee*); Willis (*Natural Capital Committee*, advising the UK Government on conservation); Langdale (authored the *UK Plant Science Research Strategy*, 2020); Cox (advisor to the *All Party Parliamentary Group for Longevity*); Bonsall (*EU Policy Advisor on Genetic Modifications*; *House of Lords Science Advisor*); Milner-Gulland (Sustainability advisor to governments *including UK, Russia, Uganda, Kazakhstan*).

Several of our Research Groups are focused on areas that can directly benefit public health and policy. For example, the Infection, Immunity and Epidemiology Group has a cross-Divisional ***Pandemic Genomics*** subtheme (including Dye, Faria, McLean and Pybus from UOA5) supported by the Oxford Martin School [IES 2.6]. In 2016 this helped establish **Zika in Brazil Real-time Analysis (ZiBRA)**, an international collaboration between Oxford, Birmingham, Public Health England and the Brazilian Ministry of Health. Building on ZiBRA's success, the Brazil-UK Centre for (arbo)virus discovery, diagnosis, genomics and epidemiology (CADDE) was established in 2019. The Centre's work is relevant to any pathogen, and it generated the first genome and phylogenetic analysis of COVID-19 in S America/Brazil—establishing the multiple routes of COVID-19 import into Brazil (Candido et al., *Science*, 2020). Our Pandemic Genomics group have also been part of international collaborations that provided important insights into recent outbreaks of **Ebola** (Dudas et al., *Nature*, 2017) and **Yellow Fever** (Faria et al., *Science*, 2018).

This concentration of expertise and support put our researchers in an excellent position to help understand the spread of COVID-19, leading to a slew of high impact papers (an article about the preprint for one paper was read over 200 million times), and a string of invitations to serve as expert advisors to **WHO and various governments (including the UK and China)**. For example, McLean

The ZiBRA project
In 2016, Faria (UOA5) and Loman (Birmingham) led a mobile laboratory that travelled 2,000 km across Brazil, sequencing over a thousand samples and designing new genomic protocols that elucidated the drivers of virus spread and guided the implementation of control measures in the Americas (Faria et al., *Nature*, 2017). Between Jun 2016 and Nov 2019, ZiBRA generated 77% of all the genomic data for Zika virus in Brazil, which was directly shared with local laboratories, the Brazilian Ministry of Health, the Pan American Health Organization (PAHO) and the WHO. The ZiBRA project also trained nearly 220 undergraduate and graduate students from LMICs in new technologies for outbreak preparedness and genomic surveillance—including 50 from public health laboratories across Brazil and Angola.

was appointed the UK Government's Deputy Chief Science Advisor for COVID-19, and Dye is leading the work of a UK-wide group of scientists to set out the facts about COVID-19 on the UKRI website, and advises the Chinese Centre for Disease Control.

4.3.3 Supporting new routes to economic and social impact

We give our research staff the freedom to explore new pathways to social impact, often providing financial and administrative support. Here we provide two examples that illustrate some of the different ways our staff have generated such impact.

- Lindsay Turnbull received £20k and administrative and event support (including from college alumni) to lead the **Aldabra Atoll Clean-up project**, following zoological research there. Her team removed 26 tonnes of plastic from this UNESCO World Heritage Site, carefully quantifying its amount and distribution. The project was broadcast live on Sky News and had a lasting impact, with new funding flowing into the Seychelles for rubbish collection, and a major German company using Turnbull's data to investigate new ways to recycle. As a result of the project the **Seychelles Government** has taken a lead in calling for worldwide action and signed up to additional measures to reduce maritime pollution.

International awareness
"*The President of the Seychelles, Danny Faure, shocked the leaders of the G7 nations with photographs of the damage being done to the island nation's Aldabra atoll by plastic pollution. …The leaders of the G7 agreed that President Faure had graphically made his point. Faure was also invited to a special session on oceans at the G7 summit by Canadian Prime Minister Justin Trudeau*."
***Seychelles News Agency*, 2018**

- More than half of completely blind patients suffer a disorder in which their biological clock fails to synchronize to a 24-hour day. These patients are severely sleep deprived and often socially isolated and depressed. Sri Vasudevan and his company *Circadian Therapeutics* develop drugs to treat sleep disorders, and together they established a close relationship with a key patient group, Blind Veterans UK (BVUK) – working with them to develop screening methodologies and to educate an initial group of 165 blind veterans and their carers. **These interventions are already generating demonstrable quality of life improvements** for both patients and carers (e.g. alternative strategies for synchronising biological clocks), even before any drug efficacy has been established.

Impact for blind veterans
"This research has immediately informed care pathways for our Veterans and their Families and the initial feedback from members has been overwhelmingly positive. This work builds on existing strands of work within BVUK and will influence current policies and programmes around blind veteran's wellbeing".
CSO, Blind Veterans UK.

4.4 Engaging with diverse communities and publics

Using our research to engage with the wider public is an important strategic goal (Section 1.2, Aim 6). We broadly take two approaches: 1) Top Down—where we both develop and take advantage of the comprehensive institutional infrastructure that supports engagement (see below and IET); (2) Bottom-Up—where we encourage our staff to develop their own initiatives and allow them the time and freedom to do so. Here we describe some of the ways in which we have encouraged and supported these activities.

- **Our researchers have significant PER support:** from the University [IES 2.2], the Divisions (both of which have dedicated PER Facilitators) and Departments (five of which have PER Officers). This support provides access to funding, training and extensive opportunities for staff interested to get involved in a range of activities that best suits their interests and skills (e.g. visiting schools, making videos, dialogue with the public).

- We benefit from hosting **the *University of Oxford Academic Champion for PER*** (Alison Woollard). She is responsible for developing and coordinating overall PER strategy, for example leading discussions with UKRI about 'pathways to impact' in grant applications. She also led Oxford's successful bid (£1.25M) to Wellcome, becoming the only approved single institutional centre for their 'Enriching Engagement' pilot. This has funded two projects in UOA5: "Genomic Detectives" (Maiden, £49K: a citizen science project that enlists the general public to characterise and curate genomic data) and "Dynamic Origins" (Srinivas, £30K: a collaboration with a choreographer to visualise embryonic development).
- **Our researchers engage with the public through the media.** Alison Woollard delivered the prestigious **Royal Institution Christmas Lectures on the BBC** in 2013, on the impact of developmental biology and genetics on the past, present and future of humankind. The programmes reached >2M viewers and led to >80 public engagement events, from local school visits to the *Life Scientific* on BBC Radio 4 and the *Chelsea Flower Show* (2019). John Parrington has written two popular science books: The Deeper Genome (2015), and Redesigning Life (2016), which has been translated into Chinese, Japanese, and Arabic. He has sold >10,000 books, and is a regular speaker at public forums (e.g. *The Cheltenham Science Festival* and *The Hay-on-Wye Literary Festival*), and at public policy conferences for specific audiences (e.g. *The Inter-American Development Bank Conference on Gene Editing*).
- We engage with the over 3M visitors per year to the University's ***Gardens, Libraries and Museums (GLAM)***. Our researchers work closely with GLAM to inform and inspire diverse communities, ranging from local schoolchildren to international tourists. UOA5-led highlights include *The Bacterial World* (2018), which attracted 174,805 visitors and was accompanied by events ranging from stand-up comedy to touch tours for blind and partially sighted visitors; and *First Animals* (2019) which attracted 161,511 visitors to learn about the evolution of animals (so popular that its initial 6 month run was extended to 15 months).
- **We support digital engagement.** For example, we generated 17 videos during the current REF period on themes ranging from *elephant conservation* to *new treatments for dementia* (>62,000 views). The animations are accompanied by teaching resources for Key Stage 3, 4 and 5. UOA5 researchers have also worked with partners to generate digital resources appropriate for the target audience. Diogo Verissimo collaborated with a leading West African pop star to produce a *music video* to encourage local populations in Sao Tome e Principe to stop consuming turtle meat.
- **Our researchers work with artists to engage with new audiences.** In 2017, inspired by Frances Ashcroft's work on ion channels, the award-winning production company *Motionhouse* developed the multi-media show "*Charge*" about the movement of electricity through the human body. Ashcroft advised the company and video specialists, and contributed an explanation of the science behind the show for the programme and website. The show toured the UK and Europe to enthusiastic reviews (e.g. "Utterly mesmerizing performance…honestly one of the best things I've seen on stage." *BBC Radio Manchester*). The show has been seen by over 22,000 people.

4.5 Contributions to the sustainability of the discipline

Several of our contributions are described elsewhere, e.g. how we train and support the next generation of researchers (Section 2.2), have invested in infrastructure to promote collaboration between different disciplines (Section 3.2 and 3.3), promote national and international networks and partnerships (Section 3.6 and 4.1), and review papers and grants and serve on various committees (Section 4.6, below).

A distinctive way in which we also contribute to sustainability is through **our ability to strategically invest in important, but vulnerable, areas of research**. Our size and resources allow us to help ensure that specialist skills in some of these areas are not lost. For example, in taxonomy a paucity of funding has created challenges in continuing teaching and research in this area. Our long-term view and allocation of internal funding enabled our researchers to develop tools and methodologies

and helped ensure the survival of the subject in the UK. This investment allowed the development of the Botanical Research and Herbarium Management System (BRAHMS) (Filer, Harris), which has now been adopted in >80 countries and is having a major impact in preserving global plant biodiversity and in species conservation [ICS: 07BRAHMS]. A second example is in research on non-human primates and ferrets, which are supported at only one other UK University. Our Biomedical Science Building provides state-of-the-art housing and veterinary care for these animals, enabling, for example, important work on auditory sensing (Bajo et al, *Nat. Comm.*, 2019; Gaucher et al., *eLife*, 2020).

Our **support for interdisciplinary research** is enshrined in several of our strategic aims (Section 1.2) and has been exemplified in many of our most significant achievements such as our investments to establish new interdisciplinary research hubs (Section 3.1), and in our support for multidisciplinary research themes and networks (Sections 4.1). Our **responsiveness to national and international priorities and initiatives is demonstrated** in Section 4.8 below, where we use our response to the COVID-19 crisis to illustrate some of the ways we have contributed, including interdisciplinary technology development; and also by our contributions to public health (Section 4.3.2) [ICS: 18EPIDEM, 20FLU].

4.6 Wider influence, contributions and recognition

Perhaps one of the best indicators of our influence in the biological sciences is the large proportion of our staff who review papers and grants and sit on Advisory Boards. Almost all **(>95%) of our research faculty** served as **peer reviewers for journals**, with 57 serving as Editorial Board members and 12 as Editors-in-Chief. More than **70 of our staff** sat on **grant awarding committees**, mainly for UKRI and the major UOA5 charity funding bodies but also for several international funding agencies such as the ERC. More than **40 of our staff sit on Advisory Boards** for Research Councils and biomedical charities in the UK, Europe, USA, Africa and China, and for NGOs such as WHO and UNITAID, and also for large international companies such as Oracle and GSK. More than **30 of our staff serve as advisors to Governments**, serving on or giving advice to committees (Section 4.3.2) with, for example, important roles in SAGE, NERVTAG and SPI-M during the COVID-19 crisis.

The contributions of several of our researchers has been recognised during this REF period with the award of a **Knighthood to Charles Godfray** (2016), and we are particularly proud that several of our female staff have been similarly recognised, with the award of **DBE to Fran Ashcroft (2015) and Angela McLean (2018)** and **CBE to Marian Dawkins (2014), Jane Langdale (2018) and Kathy Willis (2018)**.

Our research has been recognised with the award of prestigious **national and international Prizes to more than 40 of our staff**, including:

- Robertson – *Royal Medal* (2018)
- Nasmyth, *Breakthrough Prize* (2018).
- Miesenboeck, *Shaw Prize in Life Sciences and Medicine* (2020); *Heinrich Wieland Prize* (2015); *Warren Alpert Foundation Prize* (2019).
- Davies, *Biochemical Society Centenary Award* (2020); *Muscular Dystrophy Scientist of the Year* (2015); *William Allen Award* (2015).
- Klose, *Royal Society Award* (2015).
- Freeman, *Novartis Medal* (2015)
- Ashcroft, *Jacobaeus Prize* (2014); *Renold* Prize (2015); *Jacob Henle Medal* (2019),
- Sheldon, *EO Wilson Award* (2018); *Linnean Medal* (2020)
- Holland, *Darwin* Medal (2019)
- King, *Leverhulme Prize* (2018); *Linnean Bicentenary Medal* (2020)
- Fodor, *AstraZeneca award* (2019)
- Pybus, *Mary Lyon Medal* (2019)

Furthermore, 44 of our staff were **elected to learned Societies** in the UK and abroad, including:

- Berks, King, Langdale, Miesenboeck and Parekh **elected FRS**
- Fodor, Freeman, Lea, Platt, Raff and Robertson **elected FMedSci**
- Akiyoshi, Kleanthous, Somogyi, Tang, Waddell and West elected to **EMBO**
- McLean, Miesenboeck, Molnar, Platt, Poole and Sheldon elected to **Academia Europea**

More than 50 of our staff have been invited to give **Keynote addresses or to Chair national and international conferences**, such as the Croonian Lecture at the Royal Society (Davies, 2019) and Michael Brownlee Lecture at Harvard Medical School (Ashcroft, 2017).

Several of our junior faculty have won awards e.g. Akiyoshi, *Biochemical Society Early Career Research Award* (2016); De Val, *Werner Risau Early Career Award* (2017); Elliot, *British Crystallographic Society, Early Career Prize* (2019); Vasilieva, *British Society for Cell Biology, Women in Cell Biology Award* (2016).

Our **collaborative training of PGR students has been recognised** by the award of DTP status and funding to a number of interdisciplinary programmes relevant to UOA5 that involve researchers from multiple UOAs or institutions (Table 1, Section 2.2.1). Our **Wellcome DTP in Structural Biology**, for example, is a collaboration with researchers in UOA1 and at the Rosalind Franklin Institute, while the **Computational Discovery DTP,** with one of its three major themes (Advanced Molecular Simulations) run by Biggin (UOA5), is in collaboration with scientists at IBM. The **Biomedical Imaging Centre for Doctoral Training** is a collaboration with Nottingham University that supports 12 students per year funded by the EPSRC and MRC. It is primarily focused on medical imaging (and thus not listed for UOA5 in Section 2.2.1), but all these students attend the week-long microscopy course run by Micron, and perform a week-long project building a microscope.

4.7 Reproducible Research

We are keen to encourage best practice in undertaking reproducible research. In Section 1.6.3 we set out the importance we place on ensuring research is reproducible, with two examples. Although none of our submitted outputs are *focused* on reproducing the findings of key papers in their field, many support and extend the findings of such papers. We encourage the use of open-source software and standard formats: for example, the Micron facility provides access to the OME database for analysis, cataloguing and long-term storage of images, benefitting from the expertise of the OMERO consortium of universities, research labs, industry and developers.

We have also pursued this aim more widely: for example, William James is a leader in the field of iPSCs, for which several companies sell “defined” culture media whose composition is proprietary and hence impedes reproducibility. He suspected that some of these media contain anti-viral and anti-inflammatory agents, and we supported his efforts to obtain **full public disclosure** (including providing legal advice). In 2019 he approached the Director of the Wellcome Trust, and this issue has been taken up by Wellcome’s ***Open Science*** mission, by ***UKRN*** and by journals such as the ***Lancet*** and ***eLife***.

4.8 Responding to national and international priorities.

Our large size, flexible multidisciplinary structure, and collaborative ethos allows us to respond rapidly and effectively to national and international priorities and initiatives. In this final section we illustrate how these characteristics have allowed UOA5 researchers, often working closely with colleagues in other UOAs and beyond, to respond to the COVID-19 crisis.

Early on in the crisis the University established a COVID-19 Research Response Fund (total £8.2M, funding 10 projects led by UOA5 investigators, £497k). This provided funding to rapidly establish the **SARS-CoV-2 Containment-Level 3 Core Facility (SCCF)** (lead by James, the academic lead in our iPS cell facility, Section 3.2.3). The SCCF served as an initial platform for all of Oxford’s cellular

work on SARS-CoV-2, and was where **the efficacy of the ChAdOx1 nCoV-19 vaccine** in raising an immune response was first demonstrated in early Phase I/II trails. Crucially, the SCCF rapidly trained an initial group of 12 Oxford scientists from across the University in the methods for growing and handling the virus. These scientists established several other CL3 SARS-CoV-2 facilities across the University, dramatically expanding capacity. The SCCF currently works with both commercial partners (e.g. *Biotheous*, a Chinese biotech company that is **testing the efficacy of viral neutralising agents**), and with >15 different groups across the University on various aspects of SARS-CoV-2 biology, e.g. **deciphering the structural basis of antibody neutralization of the virus** in collaboration with researchers at the Rosalind Franklin Institute and Harwell, e.g. Naismith & Stuart [UOA1]; Huo et al., *Nat. Struct. Mol. Biol.*, 2020; Zhou et al., *Nat. Struct. Mol. Biol.*, 2020).

The SCCF's work in **screening new antivirals** (led by Zitzmann) is a particularly impressive example of how UOA5 researchers have worked at speed and at scale as part of an international collaboration involving more than 400 researchers to develop new potential anti-SARS-CoV-2 therapeutics (**The Covid Moonshoot Consortium**, *bioRxiv*, 2020 – not to be confused with the UK Government's Moonshot plans for rapid testing for the virus). Von Delft (UOA1) initially solved the structure of the main SARS-CoV-2 protease, and computationally generated a large number of chemical 'fragments' that should bind to the protein. Using a crowdsourcing model, medicinal chemists from Oxford and around the world were able to design compounds that should bind to the protein, and AI screening was used to identify those that could be synthesised most quickly. The best candidates were then synthesised in collaboration with industrial partners in Ukraine (working at cost and free from IP). These chemicals were tested for activity against the purified protein by Schofield (UOA8) and several of the most promising were then tested in cell assays by Zitzmann (UOA5) and her team. Working with the NIHR Oxford Biomedical Research Centre (BRC), the COVID Moonshot team made all their **data openly available** (sarscov2.assaytracker.net/). By July 2020, Zitzmann and her team had tested ~100 drugs (from Moonshot and other sources) and this data has been used to **select drugs for clinical trials by the UK Covid-19 Committee (COG-UK)**.

Meanwhile, the close relationship between the Micron bioimaging facility and Olympus led to the company lending Micron a new super-resolution spinning disc microscope system (SoRa) at the start of the pandemic to allow, to our knowledge, the only **super-resolution analysis of SARS-CoV-2 virus behaviour in cells**. This work, led by Davis and Costello (UOA5), and in collaboration with McKeating (UOA1), and Agrannof (Brighton Hospital Trust) led to a new paradigm for SARS-CoV-2 virus detection at the single molecule level (Lee et al., *submitted*) and to important discoveries about the effect of hypoxia on the virus (in collaboration with Ratcliffe, UOA1) (Wing et al., *submitted*). Micron also quickly moved its Super-resolution NanoImager system (Section 3.3.1) to Oxford's JR Hospital at the start of the pandemic, where it was instrumental in developing a new method for virus detection and identification using a convolutional neural network to distinguish between microscope images of different viruses. This method has great potential, as it can achieve labelling, imaging and virus identification in less than 5 minutes, and it can differentiate SARS-CoV-2 from influenza and other seasonal human coronaviruses with high accuracy (Davis [UOA5], Kapanidis [UOA9] and Stoesser [UOA1]; Shiaelis et al., *medRxiv*, 2020).