**Institution: University College London (UCL); Birkbeck, University of London; Institute of Zoology**

**Unit of Assessment: 5 (Biological Sciences)**

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

### 1.1 Overview

The overarching aim of our research in Biological Sciences is to tackle fundamental biological questions and to build tools and resources for the wider research community. The 235 staff (219.7 FTE) returned in this Unit of Assessment (UoA) represent a diverse group of early career and established researchers who are using microbial, plant and animal systems to advance our understanding of the fundamental principles underlying molecular and cellular function, physiology and behaviour, and how these principles are shaped by evolutionary, ecological and environmental forces. Staff are located in **UCL's Faculty of Life Sciences, Birkbeck (University of London)** and the **Institute of Zoology**, together with the **Sainsbury Wellcome Centre, Gatsby Computational Neuroscience Unit** and **Wolfson Institute for Biomedical Research**. UoA5 represents a unique centre of excellence in Biological Sciences clustered within the historic area of Bloomsbury, now part of the new London Knowledge Quarter, which contains over 100 cultural, research, scientific, business and academic institutions. This shared environment supports our researchers to use new knowledge and discoveries to tackle challenges with real-world impact on human physiology and health, conservation and the environment, as well as informing pharmaceutical and biotechnological industries, governments and society. At the heart of our approach is a commitment to provide a stimulating and supportive environment where we can recruit, retain and develop the careers of researchers, provide access to outstanding research infrastructure and expert technical support and to foster a research culture where equality, diversity and inclusion are embedded in everything we do. The vitality, sustainability and strength in depth of the world-leading research over this REF period is exemplified and evidenced by:

***Recognition of research excellence by national and international bodies:***

- Research income of over £479M, an average of £68.5M/year, £312K/FTE/year (compared to £33.4M/year and £176K/FTE/year in last REF period);
- Publication of over 6700 peer-reviewed open access research articles; 180,000 citations in total; >2.4 times the average for their field; 366 'highly-cited' articles (top 1% for their field); **Collen, Mace, Pearson, Blackburn, Partridge** and **Attwell** named as ISI Highly Cited Researchers (Clarivate);
- Vibrant doctoral training environment with 11 structured programmes (including the largest BBRSC and MRC DTPs in the UK) with an intake of >130 students per year;
- Major honors and awards e.g., Nobel Prize in Physiology or Medicine (**O'Keefe** 2014), election of 5 Fellows of the Royal Society (**Orengo** 2019, **Silver** 2017, **Fitzgerald** 2016, **Dolphin** 2015, **Hausser** 2015), Biological Secretary of Royal Society (**Partridge**), Dame Commander of the Order of the British Empire, services to environmental science (**Mace** 2016), Fellows of the Academy of Medical Sciences (**Brodsky** 2015, **Lloyd** 2020);
- QS 2021 ranking of 10th worldwide and 3rd in UK for Life Sciences and Medicine.

***Support for new research initiatives and facilities:***

- Establishment of major new research initiatives e.g., Sainsbury Wellcome Centre for Neural Circuits (£140M, infrastructure and core funding), Centre for Life's Origins and Evolution (£3.5M), Centre for Biodiversity and Environmental Research (£2M), Dementia Research Institute (£280M), UCL East Nature Smart (£400M);
- Strategic recruitment of world leading researchers (7 professors, 1 reader, 2 associate professors, 4 lecturers, 25 group leader fellows);

- Investment in buildings (>£10M) and equipment (>£14M) to ensure outstanding infrastructure and facilities (including establishment of Science Technology Platforms with permanent expert technical staff to provide access to superb core research facilities for all researchers).

***Development of a supportive and inclusive culture:***

- Recognition and reward for success through a transparent promotion process (190 junior and senior promotions);
- A broad and inclusive range of activities and initiatives designed to enable researchers to realise their potential, such as a transparent fellowship career path, structured mentorship, and provision of financial support for ECRs, e.g. 5 UCL Excellence Fellows (£1.25M), awards for new groups and fellowship extensions (£0.75M), that have attracted 25 group leader fellows and >20 junior fellows;
- Initiatives to promote Disability, Gender, LGBTQ+, Race and Religion & Belief equality for staff and students (e.g., 9 Athena SWAN awards).

***Key roles in collaborative and interdisciplinary research partnerships:***

- Most research is collaborative, involving UK (71% of staff) or international (84% of staff) partners. This has resulted in 68% of outputs involving international partners, and 30% are cross-institutional;
- Extensive (61% of staff) involvement in interdisciplinary collaborations, resulting in at least 50% of outputs in this submission involving interdisciplinary research;
- Participation in graduate training networks (40% of staff), international conference hosting (61% of staff) and participation (95% of staff), visitor exchanges (23% of staff), editorial work for leading international journals (51%);
- Extensive involvement and participation in major national and international research networks (e.g., membership of 53 European research networks with €36M UoA5 funding out of €73M total).

***Engagement with industry and policy makers:***

- Extensive collaboration with industry, commerce, and policy makers (41% of staff);
- Generation of >£6M of industrial funding and £7M central government funding in the REF period, leading to diverse impacts described below and in impact case studies;
- Competitive award of UCL Business proof of concept funding (£0.6M), translational research office funding (£0.75M);
- Consultancy with industry, government and SMEs (£0.5M total).

**1.2 Structure of Research Environment**

Our research environment is organised in five broad research themes (and associated sub-themes). Forward planning in themes is based on bottom-up investigator-led initiatives, together with overarching shared strategic goals. The change to structuring our research operations in this way, rather than around departments and institutes, reflects the success of the thematic research strategy presented in our REF2014 submission, and especially the development of new initiatives described here that facilitate cross-institutional, cross-departmental and interdisciplinary research interactions, including cross-faculty research domains, PhD training programmes and research facilities. Our themes are:

- **Cellular and Developmental Systems** - sub themes: The dynamic cell; Organelle biology and function; Tissue biology; Physical biology;
- **Disease Biology** - sub themes: Genetics of disease; Healthy ageing; Mechanisms of disease;

- **Evolutionary Biology, Biodiversity and Conservation**;
- **Neuroscience** - sub themes: Molecular, cellular and developmental neuroscience; Systems neuroscience; Sensory neuroscience and pain;
- **Structural and Molecular Biology** - sub themes: Macromolecular machines; Computational structural biology.

Research in each theme takes place across five academic departments - Birkbeck Department of Biological Sciences (**BBS**), the UCL Research Departments of Genetics, Evolution and Environment (**GEE**), Neuroscience, Physiology and Pharmacology (**NPP**), Structural and Molecular Biology (**SMB**), Cell and Developmental Biology (**CDB**) - together with five dedicated research centres/institutes - MRC Laboratory for Molecular Cell Biology (**LMCB**), Wolfson Institute for Biomedical Research (**WIBR**), Sainsbury Wellcome Centre for Neural Circuits and Behaviour (**SWC**), Gatsby Computational Neuroscience Unit (**GCNU**) and the Institute of Zoology (**IoZ**). Research is enriched by collaborations and access to facilities of other world-leading departments at UCL (including Chemistry, Physics, Mathematics and Statistics, Computer Science, Engineering, Earth Science and Medicine) and with nearby institutes, such as the Francis Crick, Rosalind Franklin and Alan Turing Institutes in which we are founding partners. These links are enabled through cross-faculty/institution strategic planning, joint appointments and secondments, investigator-led collaborations and joint supervision of PhD students. UoA5 researchers are also typically members of institutes/centres/domains that support cross-cutting research themes, foster collaboration, attract capital investment and inform strategic recruitment. Interactions are further promoted through diverse programmes of thematic symposia and workshops, seminar series, prestigious named lectures and larger annual international meetings.

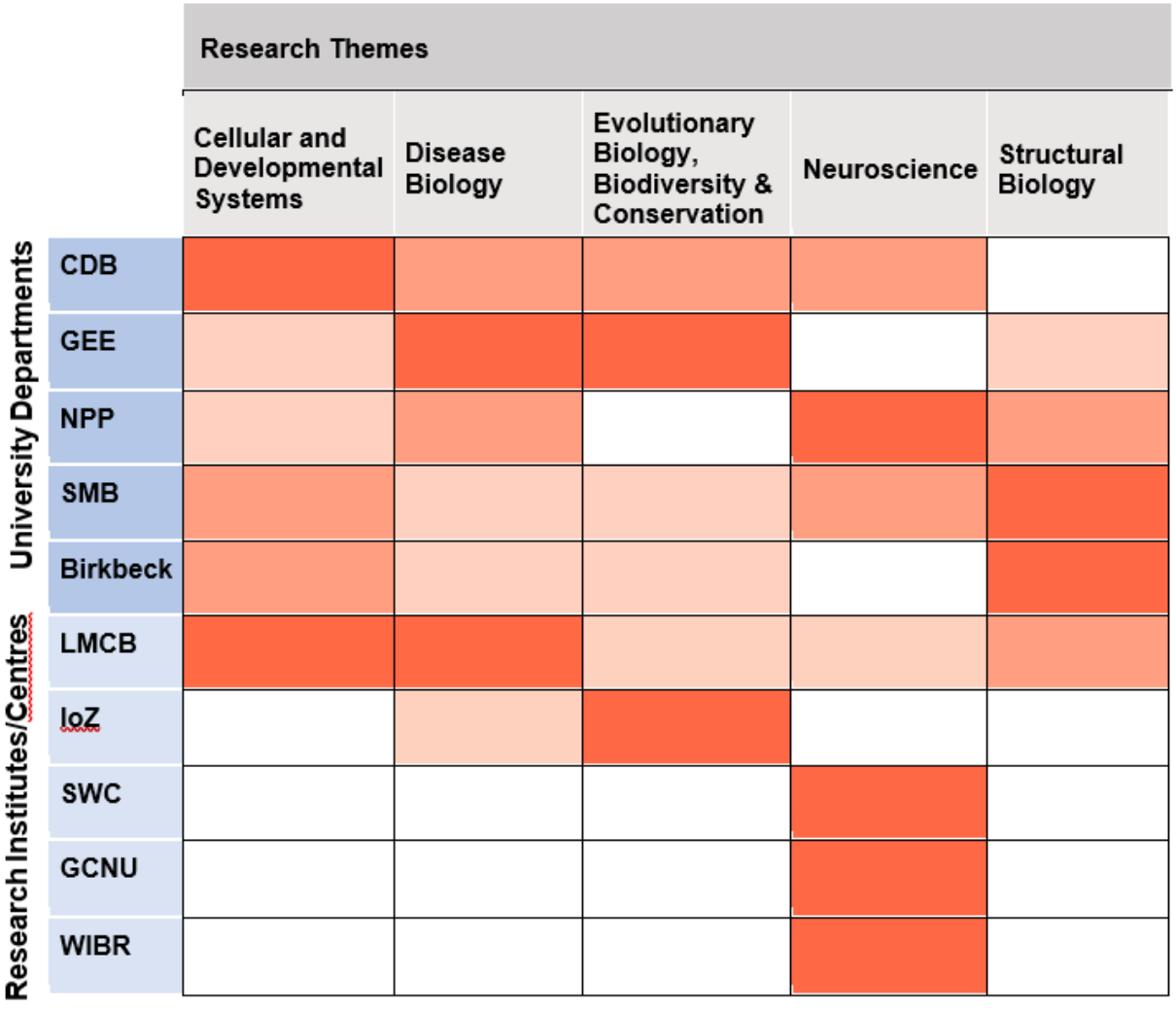

*Figure 1: Research in UoA5 is organised across five academic departments and five research institutes/centres. Darkness of shading illustrates the level of research activity in each research theme. Although research in each department is most concentrated in one theme, it generally cuts across different themes, whereas work in research institutes/centres is more focussed.*

**1.3 Research and impact strategic principles**

Our aim is to create a world-class research environment and culture that promotes the continued delivery of innovative and original science and enables researchers to realise their full potential through world leading interdisciplinary collaborative research, enterprise, impact for society and the economy. Our strategy is guided by the key principles below:

- **Major research centres and institutes** – Identify areas of excellence around strong, well-funded research groups led by outstanding individuals with long term strategic vision (rather than attempt to cover all areas in the Biological Sciences). Targeting of these areas for investment comes from complementary mechanisms: top-down to give overall direction (e.g., ZSL/IoZ partnership), and bottom-up to support researcher-led initiatives (e.g., Centre for Life's Origin and Evolution; Microbiology Domain).
- **Recruitment and career development** – Targeted recruitment of leading senior scientists, balanced by recruitment of external and internal fellowship holders and lecturers, with a well-structured career-development programme for all staff.
- **Interdisciplinarity** – Research groupings that draw upon a range of disciplines across the life and biomedical sciences, clinical, mathematical, computational and physical sciences, and supported by cross-cutting Research Domains to address global challenges.
- **Integration of approaches** – Encompassing scales from the molecular to sub-cellular, to cellular, to organs, to whole organisms, from individuals to populations and communities, and within an evolutionary framework.
- **World-leading research infrastructure** – Provision of substantial capital funding for cutting edge equipment, ongoing funding for technical support and organisation of shared facilities.
- **Shaping and responding to strategically important national and international priorities** – Encouraging membership of panels and funding bodies; international collaborations; hosting and participation in international conferences; widely disseminating information about UKRI and charity initiatives; pro-actively creating and supporting research consortia and training networks.
- **Specific support for ECRs, new staff and initiatives** – UCL Excellence, UCL/IoZ Springboard and Birkbeck ISSF Fellowship schemes, a transparent Fellowship proleptic path to permanent appointments, well-organized induction and mentoring, internal funding provision for new groups and research initiatives.
- **Translation of research for clinical and industrial exploitation and implementation of national policy** – Provision of support for technology transfer; industrial partnership management; consultancy contracting; public engagement and media relations.

**1.4 Mechanisms to disseminate research and create impact**

Our research tackles questions of fundamental importance for all levels of life, from molecules to organisms to ecosystems. It has a broad range of external academic and non-academic users and beneficiaries. Staff are encouraged and supported to engage directly with these beneficiaries to transfer expertise and knowledge that will transform and benefit society. To aid this, we have taken a multi-faceted approach: dissemination and impact is embedded in UoA5 strategy; active participation in policy making, consultancy and industry collaboration; and a systematic approach to the dissemination of research findings to academic and non-academic audiences.

**The academic community:** Rapid dissemination of our research findings impacts the speed and direction of national and international research efforts. This is achieved through the promotion and support of open access data and publication (see **1.5** for details). A UOA5 staff survey carried out in July 2020 showed that staff participated in conferences to cross foster ideas (95% of staff), organisation of conferences or scholarly meetings (61% of staff), collaborative PhD student training (40% of staff) and hosting international visitors (23% of staff).

**Industry and entrepreneurs:** Work with industry is facilitated by knowledge transfer and enterprise support mechanisms (resulting in 40% of staff having had CASE studentships, industry-sponsored research or consultancy roles). The Knowledge Transfer and Enterprise Board delivers strategic senior leadership to UoA5 researchers; the UCL Translational Research Office employs >15 staff who provide dedicated project management support for technology transfer, access to seed funding and industrial partnership management support; Base KX is the UCL start-up hub; UCLB is the technology transfer company; UCL Consultants provide a full range of academic consultancy services; UCL Innovation & Enterprise supports business partnership and knowledge exchange. Support for our research innovations has resulted in partnerships to translate discoveries into impact through spin outs (e.g., **Wood**, PainGene), clinical trials (e.g., **Szabadkai**, metabolic/mitochondrial profiling for cancer; **Bhakhta**, repurposing drugs to combat TB), translational funding (e.g., **Luscombe**, LifeArc). Some have already resulted in impact case studies (**Martin, Orengo, Chatterjee**), with at least 53 other ongoing partnerships (totalling £6M in competitive grant funding). Two UoA5 students were members of the Rice Inc team who were awarded the $1M 2018 Hult Prize.

**Government Departments, non-governmental organisations and other policy makers:** Membership of key policy committees; advice to UK Government including Ministers of State, all-party Parliamentary Groups, BEIS, House of Commons/Lords Select Committees and DHSC; these activities are mirrored internationally through work with global regulatory bodies. These activities are supported by the UCL Public Policy Unit. Our researchers have provided scientific evidence to the UK Government across a diverse range of policy areas, including the emergence and control of wildlife diseases (**Cunningham, Garner, Lawson** and **Woodroffe**) and zoonoses (**Cunningham** and **Jones**), human-wildlife conflict (**Woodroffe**), species reintroductions (**Sainsbury**), and global biodiversity trends (**Freeman**), and recent evidence to the House of Commons Science and Technology Committee has informed the UK's future preparedness for pandemics (**Jones**). Similarly, our researchers work with global regulatory bodies (e.g., World Organisation for Animal Health), and conservation conventions (e.g., CITES, Convention on Biological Diversity).

**Media and cultural organisations:** We have developed approaches to ensure effective communication and raise awareness of our research findings to a broad range of audiences. We work proactively with our Media Relations and press offices, and those of funding organisations (e.g., MRC, Wellcome). Staff appear weekly in print and broadcast media. During the REF period 46% of staff have been interviewed or featured on major news and current affairs programmes. 85% of staff and PhD students have participated in exhibitions (e.g., Biology Week, New Scientist Live, the Royal Society Summer Science Exhibition), open days (e.g., talks, performances, and pop-up stalls at UCL 'it's all academic' festival), public lectures (e.g., UCL Lunch Hour Lectures), and student mentoring/work placements (e.g., Nuffield Foundation, in2ScienceUK). The outstanding student training and experience is illustrated by the award of a 'New Researcher Outreach and Engagement Award' from the Royal Society of Biology to one of our students in 2019. Other highlights include (see **4.7** for details) Soapbox Science supporting and showcasing leading women scientists (**Pettorelli, Sumner**), developing the research content of museums and public exhibits (**Chatterjee, Odlyha)** and extensive engagement with the public through best-selling and prize-winning popular science writing (**Lane, Jones, Rutherford, Thomas**).

**1.5 Open Science, Research Reproducibility and Integrity**

Our institutional commitments to research transparency and integrity are described in the REF5a for each joint-submitting institution. In addition, all research in UoA5 incorporates the principles of the UK Concordat to Support Research Integrity, Code of Conduct for Research and Transparency in Research. These include the use of metrics for Open Research and a commitment to the principles of the San Francisco Declaration on Research Assessment (DORA).

**Publications:** Administrative staff support compliance with open access policy across UoA5 and ensure that new staff receive open access training. UCL Discovery and Birkbeck BIRON provide free and unrestricted access to more than 5400 research outputs authored by researchers in UOA5 units. Both IoZ and Birkbeck Biological Sciences staff deposit their research outputs in UCL Discovery. Of all publications accepted since 1/4/16, 97% have been deposited (or have exceptions) and 92% comply with OA Policy (or have applicable exceptions). Percentage compliance of all publications with open access policy in departments/institutes within this submission has increased from 89% in 2016 to 94% in 2020.

**Primary Data:** We are committed to the migration of data previously stored on internal servers to the public domain. The majority of our researchers (65%) have made research data, software or code available through open-source sharing platforms (e.g., GitHub, Wellcome Open Research, Figshare). UoA5 researchers have access to the UCL Data Safe Haven for sensitive and commercial datasets, whilst the UCL Research Data Repository was established in June 2019 to allow datasets to be made open access in accord with UKRI and FAIR Open access principles and the Concordat on Open Research Data for more than 10 years upon publication and linked from the institutional research publication repository (and publisher's websites where possible). Already, 31 accessible datasets have been deposited by staff in this submission. Researchers are encouraged to go beyond UKRI minimum requirements and make useful data not presented in publications accessible with appropriate metadata via the Repository and linked to via each group's website as soon as no further work is anticipated on the subject.

**Reproducibility:** Researchers have made important contributions to establishing research standards and methods to support research reproducibility, including papers that define guidelines or set community standards for research procedures or analyses. For example, **Orengo** is founder and executive Committee member of the 3D-Bioinfo Community that aims to develop structural and functional annotation, to create open resources for sharing, integrating and benchmarking (F1000 Research 2020). **Silver** has developed a suite of programmes for modelling neuronal and network activity to bring uniformity to the field of neurocomputation and spearheaded standardization of biological models of neural circuits (e.g., NeuroML Neuron 2019). Other examples include setting standards for ancient DNA analysis (**Burbano**, eLife 2015), experimental design (**Stern**, Nat Rev Mol Biol, Bioessays 2019), use of siRNA (**Bowers**, 2019), morpholino (**Wilson**, PLoS Genetics 2017) and CRISPR-Cas9 reagents (**Rihel, Wilson, Dreosti, Whitmore**, eLife 2021), mouse phenotyping (**Mott**, PLoS Biol 2015), bioimaging (**Henriques**, Nat Methods 2018), computational pipelines (**Luscombe,** Nextflow), methods for phylogenetic analyses (**Telford**, Curr Biol 2015 and **Yang** FRS, Mol Biol Evol 2018, 2020, PNAS 2018). Whilst the majority of UoA5 research builds upon and extends key findings, UoA5 researchers have also contributed directly to research integrity, governance and ethics (e.g., triage of several hundred apparently fabricated papers submitted from China to 'Cell Biochemistry & Function' (**Arnett**)); 3Rs and animal research procedures (e.g., development of non-animal models for toxicology testing (**Thompson**, Dis Model Mech 2018)); development of automated behavioural operant conditioning boxes to avoid researcher bias and interference (awarded the Crick 3R prize) (**Schaefer**, PLoS One 2018).

**1.6 Unit-wide strategic initiatives to foster interdisciplinary research**

Ten Research Domains have been established by UCL to bring together large academic communities across the Unit and wider University to address challenges that cut across both historical faculty boundaries and research themes. Four of the current Domains (*Neuroscience; Microbiology*; *Food, Metabolism and Society; Cancer*) are detailed below as they are academically led by researchers in this submission, whilst there is also significant involvement in

the *Environment*, *eResearch* and other Domains. Domains provide a platform for interaction between researchers, coordinating large-scale funding applications, informing recruitment strategy and institutional investment, and for developing national and international research partnerships. Each domain is coordinated by a steering group with representatives at different career stages from departments, institutes, and research themes, together with support staff to facilitate communication and events. Domains are supported by strategic funding for facilitators, workshops and symposia and to provide development opportunities for early career researchers.

***Neuroscience:*** This provides a strategic support structure for fundamental and clinical neuroscience across UCL, encompassing approximately 500 PIs. The steering group is led by UoA5 researcher **Smart,** with **Wilson, Geranton, Barry, Riccio** and **Margrie** also members. It has been instrumental in obtaining large-scale investment in UCL Neuroscience, e.g., Sainsbury-Wellcome Centre (£110M building and initial £50M core funding), Dementia Research Institute (£280M) and the UCL Institute of Mental Health (£1M by the Sackler Trust and £0.4M from UCL for core staff and pump priming).

***Microbiology:*** Launched in 2018, led by **Santini**, to strengthen impact in microbiology research, innovation, and public engagement across UCL and Birkbeck, it includes 120 academics and hundreds of clinical specialists and early career researchers. The research remit includes all work on microbes at cellular and molecular scales, their roles in health and disease, and the public's perception of these microbes. The domain has proved invaluable in fostering collaborations in response to SARS-COV2 (e.g., **Santini** and **Orengo,** Scientific Reports 2020; **van Dorp** and **Balloux**, Nat Comms 2020).

***Food, Metabolism and Society:*** Launched in 2017, led by **Brodsky, Thomas** and **Alic**, to promote interdisciplinary approaches to research related to healthy human metabolic function and the environmental and economic impact of human, animal and microbial metabolism. Arising from the domain, UCL is now a major partner in a consortium of seven UK universities and research institutes which secured a £5M UKRI Strategic Priorities Fund to develop a Centre for Doctoral Training (CDT) focused on developing the next generation of interdisciplinary food systems researchers.

***Cancer:*** The Cancer Domain (**Lloyd** is co-chair, **Pomiankowski** and **Luscombe** are steering group members) brings together researchers addressing the societal, technical and health challenges of cancer, and those exploring its underlying biology. UoA5 researchers are especially active in the theme of 'understanding cancer' (encompassing cancer cell biology, tissue organisation; immunity**,** tumour heterogeneity and cancer evolution; nutrition, metabolism and ageing).

**1.7 Achievements and progress of strategic objectives in REF2014 submission**
**Enabling state-of-the-art imaging** (see **3.2.3** for details)**:** Substantial institutional, UKRI, Wellcome and industrial funding (total £8M) has led to the creation of the Imaging Science Technology Platform (https://bit.ly/386rVY4). It is open to all UoA5 researchers, allowing macroscopic light sheet imaging, advanced confocal and super-resolution techniques, high throughput and cryo-EM. Highlights include: (a) The UZMIC advanced imaging centre and its associated imaging platforms (established through a partnership between UCL (£2M) and Carl Zeiss microscopy (£1.5M), bids to the UCL Capital Equipment Fund (£1.7M) and competitive external bids to Wellcome and BBSRC (£1.5M)); (b) SUper Resolution Facility (SURF) was established in 2014 with institutional and MRC funding (£2M) to provide specialist infrastructure for super-resolution imaging and technology development; (c) one of the best cryo-EM facilities in the UK has been established at Birkbeck with combined £4M Birkbeck/UCL/Wellcome funding for four microscopes including a state-of-the-art 300kV Titan Krios microscope installed in 2018.

**Facilitating the use of model systems for the study of disease** (see **1.8.2** and **3.2.3** for details)**:** A £1.5M investment in the UCL Fish Facility and £3M for lab refurbishment for fish researchers has created one of the largest fish facilities in Europe, allowing forward and reverse genetic screens in zebrafish, cavefish evo-development and healthy ageing research in killifish.

A further £2.5M investment has been provided for new laboratory facilities for *C. elegans,* enabling the recruitment of Professors **Conradt** and **Lambie**; and ECRs **Barrios** and **Labbadia**. £0.1M investment in new fly facilities has enabled six ECRs to be recruited through highly competitive external fellowships (**Alic, Kinghorn, Niccoli, Fernandez, Amoyel** and **Franz**).

**Strengthening evolutionary biology research** (see **1.8.3** for details)**:** The Centre for Life's Origin and Evolution (CLOE) was established in 2017 as a new interdisciplinary centre to study processes underlying major evolutionary innovations. Recruitment has taken place on all levels: **Greig** (Reader) – from Max Planck Institute for Evolutionary Biology (2017), **Thompson** (Professor) – from University of Manchester (2017), **Burbano** (Associate Professor) – from Max Planck Institute for Developmental Biology (2019), **Marletaz** (Royal Society University Research Fellow) – from Okinawa Institute of Science and Technology (2020). CLOE researchers will be located in a newly refurbished lab and office space (at a cost of £3.5M, completion summer 2021). This investment has already resulted in the award of a BBSRC SLoLa (**Lane**, £3M).

**Strengthening biodiversity and environmental research and ties with ZSL/IoZ** (see **1.8.3** for details)**:** Led by Director **Mace (FRS),** the Centre for Biodiversity and Environmental Research (CBER) has expanded through estate projects in 2016 and 2020 (totalling £2M) for refurbishment of office and lab space. It is now a vibrant, interdisciplinary centre with 12 PIs and senior fellows. Recruits include **Bridle** (Professor) from Bristol (2020), **Sumner** (Reader) from Bristol (2016), **Newbold** and **Pigot** who joined CBER on Royal Society Research Fellowships. To increase ties between IoZ and UCL, **Blackburn** (Professor) moved from the IoZ to CBER (2014), and four-year Springboard Fellowships were introduced with costs split equally between IoZ and UCL (recruiting **Visconti** (2015) and **Horswill** (2020)). All IoZ staff now have honorary UCL appointments, IoZ and UCL were founding partners of the London NERC DTP and MRes in Biodiversity, Ecology, and Conservation, and IoZ participate in UCL grant review and submission processes and annual promotions.

**Developing research into neural circuits underlying behaviour** (see **1.8.4** for details)**:** A major catalyst has been the creation of the SWC for Neural Circuits and Behaviour. SWC's iconic new building was opened in 2016 (£110M from the Gatsby Charitable Foundation and Wellcome). It is designed to stimulate interaction and collaboration between SWC research groups and co-located theorists at GCNU. A five-year core grant (initially £50M and £70M renewal) has enabled the recruitment of nine new group leaders: **Murray, Branco, Kampff, Isogai, Margrie Mrsic-Flogel** in 2016, **Otis, Stephenson-Jones** (ERC Starting Grant) in 2017, **Akrami** and **Hofer** (ERC Starting Grant) in 2018, and the establishment of superb core facilities with highly skilled support staff. Facilities include Advanced Microscopy (serial 2P, light sheet, head mounted 2P, 3P imaging systems), Histology, Virology (AAV and modified rabies viruses), Advanced Manufacturing (FabLab), and High-Performance Computing. In addition to the SWC, systems neuroscience has also received major investment with the establishment of new systems neuroscience and behavioural suites of labs within UCL's Rockefeller building and the WIBR (£0.4M). Researchers using mammalian models are now co-housed and facilities for non-mammalian models to study circuitry and behaviour have expanded (£5M) to facilitate recruitment of new groups using *C. elegans* (**Barrios**) and zebrafish (**Dreosti, Bianco**). We have also established direct links to systems neuroscience groups in the Francis Crick Institute, including the joint appointment of **Schaefer**.

**Expanding sensory neuroscience and pain research** (see **1.8.4** for further details)**:** This group (led by **Fitzgerald, Hunt** and **Wood**) aims to develop and exploit advanced tools and technologies to study pain, from primary sensory neurons to cortical networks, with the aim of developing new pharmacological and physiological targets and provide alternatives to opioid treatment of chronic pain. To enable this, newly refurbished laboratories (£0.1M) have been opened in the Medawar building and there has been significant recruitment of early career researchers working on pain and nociception: **Koch** recruited from the Salk Institute to a Lectureship in 2019, **Geranton** (Lecturer, now Associate Professor), **Fabrizi** (MRC Career Development Awardee (CDA), now Associate Professor, awarded Medical Foundation's

Emerging Leaders first prize 2020) and **Browne** (WIBR, Wellcome Sir Henry Dale (SHD) Fellow).

**Strengthening UCL/Birkbeck partnership for structural and molecular cell biology** (see **1.8.4** for further details)***:*** The focus has been on developing capacity for understanding large macromolecular machines. In addition to the investment in Cryo-EM and super-resolution imaging facilities (detailed above and **3.2**), facilities for time-resolved TIRF and optical tweezers (£300k Birkbeck/UCL/WT) have been established and crystallization and protein characterization and interaction capabilities renewed (£300k Birkbeck/UCL/WT). The recent establishment of UCL-wide Science Technology Platforms in NMR (led by **Christodoulou**) and mass spectrometry (led by **Thalassinos**) are amongst the best in the country. There have also been targeted recruitments of staff using NMR, X-ray, single-molecule and cryo-EM in membrane trafficking (**Brodsky**, Professor, 2014 and **Zanetti**, BBSRC Dorothy Hodgkin Fellow, 2014; Reader, 2020), intracellular transport and molecular motors (**Roberts**, Wellcome SHD, 2014; Senior Lecturer & Wellcome Senior Fellow, 2020), transcriptional regulation (**Cheung**, Wellcome SHD, 2014; **Robinson**, MRC CDA, 2018; **King**, Lecturer, 2019 and **Gouge**, Wellcome SHD, 2020) and redox metabolism (**Marechal**, MRC CDA, 2015). Several ECRs have also been recruited to bring a molecular cell biology perspective to areas with existing excellence in structural biology or vice versa; including ribosome function (**Cabrita**, Lecturer, 2017), phosphorylation (**Mylona**, Birkbeck ISSF Fellow, 2017) and bacterial secretion systems (**Ho** Lecturer, 2019).

**1.8 Major achievements and future goals of research themes**

**1.8.1 Cellular and Developmental Systems (CDS)**
Research in this theme encompasses gene expression control, cell signalling, cytoskeletal regulation, membrane trafficking and organelle regulation, cell cycle control, cell specification, tissue formation and remodelling, and understanding how these processes are hijacked in disease.

*1.8.1.1 The Dynamic Cell*
Our goal is to obtain an integrative and holistic view of dynamic cellular processes and cell behaviours at single cell resolution, and ultimately reveal systems insights into dynamical developmental processes (e.g., **Mayor**, Science 2018, **Stern,** Science 2014, **Barnes,** Cell Systems 2019). This research has been underpinned by investment (>£5M) in imaging platforms (see **3.2** for details). In addition, single cell sequencing technology (£0.25M) has been integrated into the genomics STP, offering unparalleled insights into cell states during development (e.g., **Chubb**, Development 2019, eLife 2020; **Thompson**, Developmental Cell 2018). Furthermore, a £5.5M investment in infrastructure and facilities for a wide range of model systems (see **3.2** for details) has facilitated the recruitment of researchers using key model systems; *Drosophila* (**Fernandes** (Wellcome SHD), **Amoyel** (MRC CDA) and **Franz** (Wellcome SHD)), *C. elegans* (**Barrios** and **Conradt**) and *Dictyostelium* (**Thompson**).

*1.8.1.2 Organelle biology*
Ongoing research is revealing ever more critical roles for organelle biology and cellular metabolism in all aspects of biology from embryogenesis to disease aetiology. Areas of focus include the function of lysosomes and mitochondria. The Consortium for Mitochondrial Research (CfMR) and the LysoNet initiative have been established to consolidate activities and bring together basic and clinical researchers to understand impacts on cell behaviour (**Patel**, Cell Rep 2017, eLife 2020), disease (**Mole**, Hum Mutation 2019) and the development of new therapies (**Mole**, Molecular Therapy 2018). A biochemistry core has been established (£0.3M) with Seahorse (extracellular flux analysis) and Oroboros O2K fluorespirometer. Investment in imaging (see section **3.2**) has enabled the development of innovative experimental approaches (e.g., **Duchen** and **Szabadkai**, Nat Comms 2014). New recruits include **Lambie** (UCL Senior Fellow) and **Conradt** (Wolfson Royal Society) in 2019 who bring expertise in endolysomal system dysfunction, mitochondrial stress (**Conradt** and **Lambie**, Cell Rep, 2019) and disease (**Lambie**, Nature 2020, PNAS 2020).

*1.8.1.3 Tissue Biology*
The advent of ever more effective approaches for analysing the biology of cells in intact tissues is enabling major advances in our understanding of mechanisms underlying tissue organisation during development, homeostasis, repair, regeneration and resolution following inflammation. Our research in these areas has led to breakthroughs in understanding tissue establishment (e.g., **Pichaud**, Dev Cell 2015; Nature Cell Biology 2017), homeostasis (e.g. **Lloyd**, Cell Reports 2018) and growth regulation (**Wilson,** eLife 2020) and regeneration following injury (e.g., **Lloyd**, Cell 2015). Work has been supported by investment in imaging to enable deep tissue excitation, laser ablation in tissue, intravital imaging and 3D reconstruction of tissue volumes in combination with optical clearing methods (e.g., Zeiss 880 2-photon (with OPO), 2016, £0.5M MRC). ECR recruits include **Acton** (CRUK CDF 2015) whose research bridges tissue biology with understanding of adaptive immune responses (Nature 2014, Cell Reports 2019), **Aloia** (LMCB Junior Group Leader) who brings expertise in organoid systems and liver models (Nature Cell Biol 2019) and **Franz** (Wellcome SHD) who has provided novel insights in wound healing and cancer (Dev Cell 2018). Work at the clinical interface has been strengthened. **Tedesco** (ERC Starter) is a clinician scientist who developed the first human 3D artificial skeletal muscle entirely derived from pluripotent stem cells of patients with muscle diseases (Cell Reports 2018) and is co-lead of the London Stem Cell network (https://lscn.crick.ac.uk).

*1.8.1.5 Physical Biology*
The **Institute for the Physics of Living Systems (IPLS)** was established in 2013 as a cross-faculty initiative to promote interdisciplinary approaches combining physics, mathematics, theory, modelling and engineering to understand how the physical world affects cell and tissue biology, and enable physics and mathematics graduates to transition to life science research. Interdisciplinary collaboration has enabled novel biological principles affecting cell behaviours to be revealed, including tension and force (e.g., **Paluch** and **Baum**; Nature Cell Biology 2015, Nature Cell Biology 2017, Nature 2015; Nature 2020; Science 2020) and mechanical stiffness (**Mayor** and **Charras**, Nature 2018, Science 2018, Science 2019, Nature Communications 2019, Developmental Cell 2018). The >25 PIs across the Unit have been supported by investment in advanced microscopy (see **3.2**) and staff: current IPLS director **Mao** was recruited in 2014 (MRC CDA 2014) and brings expertise in how tissues cope with mechanical stress (Current Biology 2020) and how tissue fluidity promotes epithelial wound healing after injury (Nature Physics 2019); **Saric** and **Banerjee** (both Dept of Physics) are theoretical biophysicists embedded within the IPLS.

***Future strategy in Cellular and Developmental Systems:***

- Expand and integrate expertise in quantitative (i.e., mathematical, statistical and computational) approaches in each of the subthemes.
- Strengthen the use of vertebrate model systems, focusing on aspects of stem cell and organoid biology, and neural development to complement our research base in other model systems.
- Consolidate and expand interdisciplinary and translational organelle research by bringing together researchers and resources across the UoA through the establishment of a new 'Inner Cell Centre' and expansion of metabolomics and respirometry capabilities.
- Increase ties with the Centre for Integrative Anatomy (see section **1.8.3**) to enable cell and developmental biology to bridge temporal and special scales to encompass evolutionary and human genetics.
- Expansion of IPLS research themes through engagement and targeted collaboration with departments of engineering and material science, as well as the Turing Institute and Crick.

**1.8.2 Disease Biology**
This theme encompasses research into understanding the mechanisms underlying disease through animal and cell-based models, the genetic basis of disease, ageing and ageing-related disease, and ultimately novel therapeutic strategies.

*1.8.2.1 Mechanisms of Disease*

Understanding the biological mechanisms underlying disease onset and progression is central to our goal of moving rapidly from discovery science to clinical translation. Research in this area links multiple departments and faculties, including those outside the Unit including the UCL Cancer Institute (e.g., **de Bruin** and **Tada** work on cancer cell replication and cell interactions (Cell Reports 2016; Nature Comms 2018). A focus has been to increase interactions with clinicians through the development of models of disease (e.g. **Wilson** and **Rihel** Nat Comms 2016, Neuron 2016), and the recruitment of clinician researchers (e.g. **Tedesco**) to aid interactions with clinicians and pharma, and encourage clinicians to undertake PhDs (e.g. Tuschl, now an academic clinical lecturer and MRC clinical fellow). Research into viral infection has led to the development of novel effective antiviral therapies and understanding viral host interactions (**Marsh**, PLoS Pathogens 2019; **Mercer**, Nature Microbiology, 2018, Nature Microbiology, 2019, Nature Microbiology, 2019). We also encourage commercialisation, for example Virology Research Services Ltd is a contract research organization founded by LMCB researchers providing consultancy and experimental services in virology and early-stage antiviral/vaccine discovery.

*1.8.2.2 Genetics of Disease*

The **UCL Genetics Institute (UGI)** is a cross-faculty centre dedicated to the development of statistical and bioinformatic approaches for genome data analysis. UGI researchers apply these methods to understand the genetics of human diseases, improve crop varieties, antibiotic resistance, and provide genetic and biochemical insights into human evolution (e.g., **Thomas** and **Brodsky** eLife, 2019). UGI has expanded the scope of its research by incorporating psychiatric genetics (**Kuchenbaecker)**, statistics (**Curtis**) and transcriptional regulation (**Luscombe**, Joint UCL/Crick appointment). New appointments include **Mott** (Professor) who investigates the effects of genomic variation in plants and animals (Nature 2015, Cell 2016, Nat Genetics 2016); **Andres** (Senior Lecturer) who uses genomic-level statistical approaches to uncover mechanisms underpinning population diversity (Science 2017); **Secrier** (UKRI FLF) who employs machine learning and data integration strategies to study cancer (Nat Gen 2016); and **van Dorp** (UCL Excellence Fellowship), whose collaborations with UGI Director **Balloux** have enabled reconstruction of transmission chains in hospital wards and description of global epidemics, past and present, including COVID-19 (Nature Comms, 2020).

*1.8.2.3 Healthy Ageing*

The **Institute of Healthy Ageing (IHA)** is a centre of excellence for research on the biology of ageing and ageing-related diseases. Its aim is to develop a new translational biogerontology using the ageing process as a point of intervention to protect against the diseases of old age. Under the leadership of **Partridge** and now **Bahler**, the IHA has expanded in basic science through the recruitment of **Alic** (Biosciences Research Fellow and now Associate Professor, Nature 2017) and **Labbadia** (BBSRC David Phillips, PLoS Comp Biol 2019, Dev Cell 2020) who use model organisms to uncover novel mechanisms underpinning lifespan, whilst **Niccoli** (Alzheimer Research UK Senior Fellow, Science 2014) and **Kinghorn** (Wellcome Clinician Scientist Fellowship, PNAS 2019) bridge to clinical settings and neurodegenerative disease. Basic science discoveries have led to links with industry for the development of novel therapeutics for neuro-degenerative disorders (**Ketteler**, Nature Chemical Biology 2015, Nature Comms 2017).

***Future strategy in Disease Biology:***

- Establish the 'UCL HumGen Core' to bring together experts and research programs on human disease genetics which are currently dispersed across different departments, and to provide a centre of expertise that enables researchers to share knowledge and create synergies. It will allow links to be made with researchers developing models for the study of genetic disease (including ageing) and to enable subsequent clinical translation of genomics to benefit healthcare.
- Establish the 'UCL Metacore' for the study of genomic DNA from complex mixed community samples to understand health and disease. Genomics data from complex samples requires dedicated expertise and refining of data-driven methodologies. We will

bring together and expand research in environmental sampling, microbiomes, plant health and breeding, host-microbiota interactions, and ancient DNA (museomics).

**1.8.3 Evolutionary Biology, Biodiversity and Conservation**

UCL and IoZ have long been leaders, innovators and partners in complementary aspects of evolutionary biology, biodiversity and global conservation challenges. This REF period has seen the depth and vibrancy of the collaboration between the two organisations markedly increase, which allows us to jointly tackle fundamental questions, with potentially transformative outcomes for wildlife and people.

*1.8.3.1 Evolutionary Biology*

Evolutionary biology research aims to understand processes underlying major innovations and transitions that have led to the diversity of life. This research spans shallow and deep evolutionary time and is carried out in two newly established, but complementary, research centres:

**Centre for Life's Origins and Evolution (CLOE):** The establishment of CLOE in 2017 (Director **Telford**) has brought together researchers across Biosciences, Computer Sciences and Earth Sciences, championing the integration of diverse technological approaches to evolutionary biology (e.g., molecular biology, genomics, microscopy, palaeontology, embryology). A £3.5M investment has resulted in new laboratories, office and communal space (completion summer 2021). Research ranges from understanding the origin of life and eukaryotes (e.g., **Lane** and **Pomiankowski**, Nat Ecol and Evol 2019) to understanding how evolution has shaped the diversity of multicellular life (e.g., **Telford**, Curr Biol 2015 and **Yang**, PNAS 2018). New appointments include: **Burbano** (Royal Society Wolfson Fellowship) who uses ancient plant DNA to study host-parasite dynamics, crop domestication and invasive species (Science 2017); **Marlétaz** (Royal Society URF) who uses genomic approaches to better resolve the phylogeny of metazoans and understand the functional impact of whole genome duplications (Nature 2018); and **Thompson** who combines modelling and lab experiments to reveal the molecular details of kin recognition and social strategies (Nat Comms 2017, PNAS 2019).

**Centre for Integrative Anatomy (CIA):** The CIA brings together researchers from diverse academic fields working on all aspects of anatomy: comparative, evolutionary, developmental, medical, and forensic. Under Director **Evans**, whose studies of amphibian fossils has shed light on the vertebrate anatomy evolution (Science 2020), the CIA has renewed UCL's strength in evolutionary vertebrate anatomy. Investment has been made to refurbish labs and provide advanced imaging technologies including a high-resolution microCT scanner, dedicated CT lab and 3D printer to allow form-function relationships in modern and fossil taxa to be investigated (total cost £375K). CIA researchers can now employ diverse and cutting-edge approaches to study anatomy in order to understand structure and function, embryonic development, phylogenetic relationships, ecology, and evolution. New appointments include **Felice** (2018: evolvability and disparity across clades, PLoS Biology 2020) and **Porro** (2018: biomechanical finite element and musculoskeletal modelling).

*1.8.3.2 Biodiversity and Conservation*

Research in biodiversity and conservation combines field, laboratory, and computational approaches. Staff actively engage in using their findings to influence policy and management. Research is undertaken across two complementary and closely aligned centres of excellence; the Centre for Biodiversity and Ecology Research (CBER) and the Institute of Zoology (IoZ). Joint appointments strengthen these research links, including **Blackburn** whose work with **Redding** led the development and analysis of GAVIA, the most comprehensive resource on the global distribution of alien species in any major taxon (Nature 2019); **Visconti**, who uses large-scale ecosystem models to predict future biodiversity loss (Nature Climate Change 2017); and **Horswill**, who works at the interface between environmental variation, demography, and population dynamics (PRSB 2018).

**The Centre for Biodiversity and Environmental Research** (CBER) was established in 2013 with a £1.5M investment in a new building and four new posts. Led by Director **Mace** FRS (who published the first science-based paper on the risk that human perturbations will destabilise Earth systems, Science 2015), further estate projects (2016 and 2020, totalling £2M) have expanded CBER facilities through refurbishment of office and lab space. CBER research lies at the interface between biodiversity and environmental change. Its core themes include: the consequences of biodiversity loss; environmental change and biodiversity; and limits to adaptive change. Significant appointments include: **Sumner** who studies mechanisms of behavioural plasticity in social insect ecology and resilience to environmental change (Nature 2018); **Bridle** who studies ecological and genetic limits to adaptation in plant and animals species and how this affects distributions and niche widths (Ecology Letters 2014); and **Newbold** and **Pigot** (both Royal Society URFs) who apply computational models to elucidate the mechanisms underpinning biodiversity at large spatial, temporal, and taxonomic scales (Nature 2015, 2020). **Newbold**'s work has transformed our understanding of the effects of land-use on terrestrial biodiversity (Nature 2015, Science 2016), whilst work with other CBER PIs (**Jones, Blackburn, Redding**) has shown that land-use change favours zoonotic disease hosts (Nature, 2020).

**The Institute of Zoology (IoZ)** is an international centre for conservation science which made an independent return to REF2014. However, the strengthening links between IoZ and UCL has drawn the two organisations together. Research is focussed in five areas: wildlife health, endangered species recovery, coexistence of wildlife and people, global biodiversity monitoring, and mitigating and adapting to climate change. New appointments include **Nicoll** who studies the biology and management of small populations (Current Biology 2014); **Hansford** who explores extinctions in the archaeological period (Science Advances 2018); and **Redding** (Wellcome SHD Fellow) who develops eco-epidemiological mechanistic models to predict the emergence and spread of zoonotic disease (Nature 2020). His work with **Cunningham** (who identified the biological determinants of cross-species viral transmission in bats and rodents (Ecology Letters 2015)) has led to a wider understanding of the interplay with socio-economic factors in predicting Ebola outbreaks in Africa (Nat Comm 2019). The recruitment of **Turvey** (Royal Society URF) adds strength to IoZ efforts through **Jepson, Norris** and **Wang** to understand human impacts on biodiversity and ecological systems (Science 2018, Science 2018, Nature Sustain 2020, Nature 2017).

***Future strategy in Evolution, Biodiversity and Conservation:***

- Establish a centre for theoretical modelling and quantitative biology, harnessing already strong ties between evolutionary biologists and mathematical, computational and statistical sciences. This initiative, led by **Barnes** (Wellcome SRF) and bolstered by the recruitment of **Shou** from the Fred Hutchinson, USA (Academy Medical Sciences Professorship), will encompass systems approaches, cell biology and neuroscience, microbial population dynamics, ecological dynamics and genomic computational studies.
- Establish and integrate the new **Nature-Smart Centre.** Building of this bold cross-disciplinary institute (directed by **Jones**) began in this REF period and will open as one of the 11 cross-faculty institutes within the new UCL East Campus (£400M investment) in 2023, linking biodiversity to computer science, urban ecology to city planning, and environmental economics to human health, to develop tools for a more sustainable and resilient future.
- Establish and integrate the **National Institute for Biodiversity and Public Health**. This £200M partnership between IoZ, UCL, and Royal Veterinary College, led by **Cunningham** will create a globally unique transdisciplinary research and innovation hub, enabling us to identify and mitigate the eco-epidemiological and socioeconomic drivers of biodiversity loss and its associated zoonotic diseases.

**1.8.4 Neuroscience, Physiology and Pharmacology**

Research activity spans studies of atomic level structure, to molecular and cellular biology, to integrated neural circuit activity and how this impinges upon behaviour, physiology and disease.

*1.8.4.1. Molecular, Cellular and Developmental Neuroscience*

Research focusses on understanding the mechanisms underlying nervous system development and function. It is underpinned by world leading research facilities, including outstanding core imaging facilities, the creation of a London Centre for High Throughput Electrophysiology (Nanion, BBSRC £0.6M) and a core-funded Multi-Electrode Array facility for dissociated neurons and human stem cell recording (£151K). This REF period has seen a focus on structural approaches to the molecular basis of neuronal signaling through collaboration with the ISMB and recruitment (e.g., **Gold** Wellcome SHD fellow, whose work with **Smart** led to the first atomic structure-based explanation for neurosteroid action (Nature Struct Molec Biol 2017). There has also been investment in facilities (>£7M) to support researchers using different model systems. This includes **Barrios** (lecturer) and **Poole** (WT SRF) using *C. elegans* and **Fernandes** (Wellcome SHD Fellow) using *Drosophila* who have identified glia as a novel source of neural progenitors in these model systems (Nature, 2015, eLife 2020, Science 2017). Facilities for fish (**Wilson, Dreosti, Rihel**, new recruit **Bianco** (Wellcome SHD Fellow, then SRF), chick (**Stern**) and mammals (**Attwell, Richardson, Salinas, Riccio, Kessaris, Li, Jessen,** new recruits **Koch, Browne**) have enabled major advances in cellular neuroscience (e.g., **Richardson**'s work on oligodendrocyte function (Nat Neurosci 2016, Science 2016) and diverse clinical implications (e.g., **Attwell**'s discovery of a novel level of control of blood flow, Nature 2014; Nat Neurosci 2016 (together with **Gourine**); eLife 2014; eLife 2016; Science 2019).

*1.8.4.2 Systems Neuroscience*

Our word-leading systems neuroscience research aims to understand how neural circuits are connected, how they encode sensory information and perform computations before giving rise to complex and adaptive behavioural phenotypes. It builds on our strength in understanding spatial navigation (e.g., **Barry** and **O'Keefe,** Nature 2015; Science 2018; **Hausser**, Cell 2020) and has greatly expanded through the opening of the SWC (led by **Mrsic-Flogel** and **Margrie**) (£110M Wellcome/Gatsby). The SWC is supported by five-year core grants (initially £50 million, renewed £70M in 2020) (see **1.7** for details) which has enabled new group leaders to be recruited (**Murray, Branco, Isogai, Margrie** in 2016, **Mrsic-Flogel, Otis, Stephenson-Jones** (ERC Starting) in 2017, **Akrami** and **Hofer** (ERC Starting) in 2018, and the establishment of superb core facilities with highly skilled support staff. This includes the Fabrication Laboratory and MakerSpace, which is an innovation lab for the design and manufacture of custom tools and instrumentation for the research community. SWC also collaborates with members of UoA5 through its invitation-only affiliates program. Affiliates are invited to SWC events and have access to the FabLabs and other core resources. They can host SWC PhD students for lab rotations and act as their joint supervisors for placements and are also invited to jointly host seminar speakers at the SWC. Current affiliates include **Bianco, Clark, Hausser, Macaskill, Rihel, Silver** and **Wilson** who are collaborating with SWC researchers on a wide variety of ideas. **I**n addition, systems research has been bolstered by laboratory refurbishment, a new BSU (total £4.2M) and the recruitment of **Dreosti, Bianco, Macaskill** (Wellcome SHD or SRFs). The standing of our research in this area is demonstrated by the fact that of the 22 group leaders forming the 'International Brain Laboratory' (£9.6M Wellcome), five are in this UoA (**Hausser, Mrsic-Flogel, Höfer, Latham and Dayan**). This REF period has also seen the development of machine learning and AI approaches, with a Neuro-AI sub-domain set up within Neuroscience Research Domain (led by **Barry** and **Smart** within this Unit) and interactions with commercial partners, including Google DeepMind (**Barry**, Nature 2016). Research on neural circuits in vivo benefits from interactions with the Gatsby Unit whose work encompasses theoretical and computational neuroscience, computational statistics, machine learning and artificial intelligence (**Sahani**, Neuron 2016, Nat Neurosci 2019, **Latham** Nat Neurosci 2014, PLoS Comput.Biology, 2016, **Dayan**, PNAS 2016, Nat Comm 2018).

*1.8.4.3 Nociception, sensory neurophysiology and pain*

Research encompasses identifying nociceptive circuit pathways, and spans from peripheral sensation to central mechanisms of pain perception, and from fundamental discovery science to drug development and clinical translation. Approaches include animal and human models, molecular genetic studies, pharmacology, whole animal physiology and human EEG mapping of sensory fields. Established researchers (e.g. **Fitzgerald** and **Dolphin** both elected FRS in this REF period) have been joined by newly recruited early career scientists. This includes lecturers

**Koch** (recruited from the Salk; Cell, 2015 Science 2015, Neuron 2017) and **Geranton** (whose discovery of a stress regulator that drives chronic pain by modulating spinal glucocorticoid signalling has therapeutic potential (Science Transl Med, 2014)) and **Browne** (Wellcome SHD). The addition of a clinical neurophysiologist (**Whitehead**) and computational scientists (**Ianetti, Fabrizi** (MRC CDA) has enabled the study of pain and sensory processing in the developing human brain, resulting in the discovery of a major brain centre driving human postnatal brain maturation (**Whitehead** and **Fabrizi** eLife 2016). Major collaborative awards totalling >£3.6M bring these scientists with different skillsets together (e.g., London Pain Consortium, WIBR Molecular Nociception Group (**Wood, Cox, Zhao**), Infant Pain & Sensory group (**Fitzgerald, Fabrizi**), epigenetics, stress and pain (**Geranton, Hunt**)).

***Future strategy in Neuroscience, Physiology and Pharmacology:***

- Developing and integrating new methods: cryo-EM methodology for determination of neurotransmitter receptor structure and their molecular pharmacological modulation by drugs/ligands, and for tomographic imaging of synaptic structure; serial block-face two-photon microscopy for whole brain fluorescence tomography; mesoscope technology to explore the neural connectome and to image neural activity at cellular resolution in genetically-defined neuronal populations; new mammalian and fish 'behavioural, pharmacological and metabolic animal phenotyping platforms' for genetic disease, obesity, diabetes, ageing and exercise studies.
- New virtual centres to promote collaboration between experimentalists, theorists, engineers and large-data scientists to drive discovery: Institute for Mental Health for the exploration of the molecular bases for mental health disorders; Centre for Neuro-AI (with computer science, industrial (Google) and academic partners (the Alan Turing Institute)) to investigate how neural computation promotes flexible, adaptive behaviour, at the level of brain regions, neural circuits, cells, and single synapses.

**1.8.5. Structural and Molecular Biology**

Our research focuses on understanding how macromolecular complexes function. It brings together >70 PIs at UCL and Birkbeck within the **Institute of Structural and Molecular Biology** (established in 2003). Investment in facilities and recruitment over this REF period has allowed cutting-edge methods to be introduced and developed. This includes >£5M (detailed in Section **1.6** and **3.2**) in new cryoEM technologies that have revolutionised structural biology. Existing crystallization and protein characterization and interaction capabilities have been consolidated and renewed in the ISMB-BiophysX facility (£300k Birkbeck/UCL/WT). The recent establishment of UCL-wide Science Technology Platforms in NMR (led by **Christodoulou**) and mass spectrometry (led by **Thalassinos**) will enable future coordinated investment in these areas. Recruitment has added methodological expertise in cryoEM to the pre-existing group (**Saibil, Orlova, Moores** and **Topf**). This includes **Zanetti** (BBSRC Dorothy Hodgkin Fellow, Nat Comm, 2018) and **Robinson** from Stanford (e.g., Methods, 2019). We have also expanded the use of single molecule and super-resolution imaging. **Roberts** (Wellcome SHD) brings expertise in time-resolved single-molecule TIRF microscopy (eLife 2014) and **King** brings newly developed technologies for correlated fluorescence imaging and opto-mechanical manipulation of DNA complexes (PNAS 2019). We have actively promoted an environment in which novel methods can be developed, exemplified by the development of quantitative super-resolution imaging and software tools for data analysis (**Lowe**, eLife 2015), pioneering methods for MS (**Thalassinos** and **Topf**, Structure 2018) and NMR (**Hansen** and **Christodoulou**, Nature Comms 2019; Scientific Rep 2016).

*1.8.5.1 Macromolecular machines*

Existing expertise in RNA polymerase (**Werner**), histone methylation (**Hansen**) and non-coding RNAs (**Arnvig, Nobeli**), has been added to by new recruitment: **Ramos** (Professor, from NIMR) has built a program of NMR, biophysical and transcriptomic analysis of mRNA transport (Nat Comm 2018); **Cheung** (WT SHD) has provided novel insights into the dynamic assembly and regulatory mechanisms of RNA polymerases (eLife 2017; Nature 2020); **Robinson** (MRC CDA) brings expertise in structure and dynamics of chromatin remodelling (Cell 2016); **King** (Lecturer) brings expertise in single-molecule study of the DNA topoisomerases (PNAS 2019); **Gouge** (WT

SHD) performs structural studies of redox sensing and transcription (Cell 2015). Strength in protein folding, the chaperoning and activation of proteins, and of pathological protein misfolding in human diseases (**Christodoulou, Lowe, Raleigh, Saibil, Thalassinos** and **Vaughan**) has been augmented by the recruitment of **Cabrita** (Lecturer) who studies misfolding during protein biosynthesis (Nat Struct Mol Biol 2016). Finally, the grouping studying transport of proteins in eukaryotes **(Moores, Brodsky, Lowe, Boucrot, Zanetti)** and bacteria **(Hayward, Waksman)** has produced seminal discoveries in this REF period, e.g. discovery of a new endocytic route (**Boucrot** Nature 2015, Nat Cell Biol 2018) and how proteins and DNA are exchanged between bacteria and with human hosts (**Waksman**, Nature 2014 with **Orlova**, Cell 2017 with **Zanetti**, Cell 2016 with **Santini**). Expertise in bacterial secretion systems has been bolstered by new recruit **Ho** (Lecturer, PNAS 2017).

*1.8.5.2 Computational Structural Biology*

Birkbeck and UCL have a long history of significant joint developments in computational analysis and structural prediction of biological molecules, particularly proteins. Activity is centred around the joint UCL/Birkbeck Bloomsbury Centre of Bioinformatics led by **Jones** (joint appointment UCL Bioscience/SMB and Computer Science, returned in UoA11) whose work with DeepMind has led to the creation of AlphaFold (Nature 2020), currently the world's best method for the prediction of protein structure from sequence. We host internationally important protein structure databases for integrative structure analysis. UCL is one of the 11 institutes that constitute the UK Node of the ELIXIR infrastructure for bioinformatics, the inter-governmental coordinating body funded by national governments and the EU for bioinformatics resources. CATH-GENE3D (**Orengo**) is the major service from UCL and contains domain predictions for 82 million gene sequences presently available in public databases. The Protein Circular Dichroism Database (PCDDB) (developed by **Wallace**, NAR 2017) and Intrinsically Disorder Protein ELIXIR Community are also part of the ELIXIR landscape (F1000 Research 2019). In-house development of new tools of this kind and their expert application has led to insights into non-coding RNA (**Nobeli, Arnvig**, NAR 2018), voltage gated-sodium channels (**Nobeli, Wallace**, PNAS 2016), von Willebrand Factor function (**Gervasio, Hansen**, J Phys Chem 2018), redox regulation (**Gout, Orengo**, Biochem J 2017), and the evolution of enzyme function (**Orengo** and **Williams**, PNAS 2014).

***Future strategy in Structural and Molecular Biology:***

- Expand the application of structural, super-resolution and cryoEM imaging to problems in cellular function in neuroscience and neuropharmacology, cancer biology, and molecular microbiology.
- Build research capacity in computational structural biology with a focus on emerging machine learning, AI and simulation methods in the prediction of the properties of molecular systems and integrating data from diverse structural, genetic and cellular studies. Create an STP to support application of computational structural biology in cross disciplinary research.
- Build capacity in understanding the evolution of macromolecular function in nature through synthetic biology and evolutionary approaches to understand how structure constrains gene evolution, and to provide insights into the artificial selection of new, technologically useful functions (through increased ties with Chemistry and Biochemical Engineering).

## 2. People

UCL, Birkbeck and IoZ are committed to developing and sustaining a culture that enables staff at all career stages to develop an international research profile through their outputs, funding and contributions to research impact. This goal defines our approach to staff appointments, mentoring and promotion.

### 2.1 Staff

**2.1.1 Recruitment**
Recruitment is based on a holistic evaluation of academic excellence. Application evaluation and interview panels are composed to ensure fairness in EDI, and training in fair recruitment is compulsory (with unconscious bias training compulsory for panel chairs). UCL (2013) and Birkbeck (2017) have received the HR Excellence in Research Award. There have been seven new appointments directly to professorships to provide leadership in strategically important areas (e.g. **Conradt** from Munich as head of CDB Dept, **Thompson** from Manchester (now Head of GEE Dept), **Mrsic-Flogel** from ETH Zurich as SWC Director), and seven to lectureships/senior lectureships. We have also recruited 25 junior group leaders via competitive externally funded independent research fellowships (e.g., Research Councils, Royal Society, Wellcome, Cancer Research UK and other biomedical charities) and highly competitive internal independent Fellowship Schemes (e.g. UCL Excellence Fellowships, Birkbeck ISSF Fellowships, UCL/IoZ Springboard Fellowships) representing an investment of >£1.25M. We are also proud of our researchers that have taken up influential positions at other universities and research institutes in the UK and internationally. We view this is a positive reflection of the vibrant research culture at UCL, and its ability to promote success. Examples include **Oates** (EPFL), **Stanewsky** (Muenster), **Paluch** (Cambridge), **Baum** (MRC-LMB Cambridge), **Cabreiro** (MRC-LMS & Imperial College London), **Mercer** (Birmingham), **Piper** (Monash), **Norris** (Natural History Museum).

**2.1.2 Career development, mentoring and appraisal**
UCL, Birkbeck and IoZ have adopted the principles of the Concordat to Support the Career Development of Researchers and the European Charter for Researchers and Code for Recruitment. All staff are appraised annually by the Head of Department or manager to set research targets and training goals, and plan progression towards promotion. In addition, comprehensive mentoring systems for academic, research staff and postdocs have been created. Mentors are more experienced staff working in a similar area as the mentee, but without direct management involvement. Mentors are provided with training (e.g., online mentoring platform (uMentor) developed by UCL) and many staff also participate in the University of London B-MEntor programme for BAME academic and research staff founded by UCL. ECRs also have access to bespoke support networks through Research Domain and Divisional structures.

**2.1.3 Staff training**
Staff are provided with protected time to complete 10 days per year of skills training, and have access to the Researcher Development Framework, a professional development tool to enhance the knowledge, attributes and skills required for success as professional researchers. In-house bespoke leadership training is provided (e.g., over the last 3 years alone Future Leaders (9 staff), UCL Women in Leadership programmes (7 staff); Women in Research (8 staff)). There is also training for junior staff, including the Arena2 course for probationary lecturers (19 staff), whilst UCL is the only UK institution to host the EMBL Group Leaders course. We also actively promote a sabbatical policy, which allows paid leave free from teaching and administrative duties for up to a year. This enables staff to maintain a high calibre of research, scholarship and innovation, or refresh their research outlook and expertise, often at overseas universities. Examples include **Bahler** who spent five months at Stanford University to learn about research with the turquoise killifish (*Nothobranchius furzeri*), including husbandry and genome-editing. This enabled us to establish a colony of this promising new model to study ageing and ageing-associated diseases, and resulted in a Cancer Research UK Pioneer Award; **Waksman** who spent the summer of 2014 at the Institute of Advanced Study Strasbourg in order to enable expansion of the use of high-resolution EM methods in his research (see **3.2**).

**2.1.4 Promotions**
The UCL Academic Career Framework (ACF) was comprehensively revised in 2017/18 to support every type of academic career path via a robust set of processes with explicit criteria. The IoZ Science Research Grading (Promotions) Policy is also aligned with the ACF. Birkbeck followed a similar framework to introduce a new ACF in 2018/19. For all three institutions the ACF is designed to ensure parity whether staff deliver research and education in equal measure,

specialise in public engagement or enterprise, or focus on teaching and institutional citizenship, or enterprise and external engagement (impact). Promotions are not contingent on securing grant funding but on ability and achievements, and the DORA commitments to research evaluation are explicitly recognised, as are contributions to Open Science. Since 2014, 38 staff have been promoted to professor, 35 to reader/senior lecturer/associate professor/principal research fellow, and 27 to lecturer/senior research fellow/senior associate.

**2.2 ECRs and Fellows**

All UoA5 departments and institutes have established dedicated programmes for ECR development. Holders of independent research fellowships are considered equivalent to those on academic contracts and are expected to move onto academic positions after their fellowships. To ensure fairness, potential fellows are invited to apply through open advertisement and assessed following the same procedures as applying for a lectureship position (seminar, meeting staff, interview). We provide academic and administrative support for the preparation of the fellowship application and dedicated strategic financial support for ECRs through the Wellcome ISSF fund and matched funding (£0.6M during REF period). This facilitates additional grant applications and ultimately helps ensure long term success. ECRs/Fellows are able to recruit PhD students through UCL or external programmes. We will provide up to two years of salary support beyond Fellowships (£160K in REF period) to allow Fellows to hold additional Research Council grants and help ensure that fellowship holders are best placed to transition to a follow-on Fellowship or permanent position. All fellows with suitable competitive awards (e.g., Wellcome Henry Dale, MRC CDA, Royal Society URF, CRUK, or ERC starting grants) are assessed for a permanent appointment through open seminar and panel interview (including external referees) in the penultimate year. The assessment criteria (research output, grant income, contributions to teaching and departmental/divisional citizenship) are clearly defined upon appointment. All independent research fellowship holders in the last five years have progressed to become PIs within UoA5 or elsewhere.

**2.3 Postdoctoral researchers**

Postdoctoral researchers (>300 on REF census date) are central to our research efforts. A senior academic in each department/institute acts as an advocate for the local postdoctoral community and gives postdocs input into decision making. Career development is strongly encouraged: delivery of appropriate amounts of undergraduate teaching and supervision of UG/MRes/MSci projects (>300 have attended Post-graduate Teaching Assistant training during this REF period), skills training to prepare for future careers as independent researchers or a diversity of other career paths (e.g., scientific writing, entrepreneurship, industrial or policy-related employment). The UCL Research Domains have also established early career networks for careers advice, professional training, and the dissemination of information regarding jobs, personal development and funding opportunities. The value placed on postdocs is illustrated by their eligibility for accelerated increments/promotions or one-off payments to reward exceptional performance, whilst the LIDo DTP Associates programme showcases the contributions of “hidden supervisors” (postdocs and technical experts).

**2.4 Clinical researchers**

Clinical researchers from key hospital partners (e.g., UCLH, NHLI, and the Royal Free Hospital) and NIHR Biomedical Research Centres are fully integrated into UoA5 labs. This includes clinical fellows (e.g. **Kinghorn**, WT Clinical Research Career Development Fellow; **Wood**, MRC Clinical Research Training Fellowship), clinician PhD students and major long-term collaborations with NHS clinicians (e.g. **Cutler**, cellular mechanisms of haemostatic disorders; **Fitzgerald**, pain in infants and children; **Chatterjee**, exploring links between culture and health). This facilitates the transition from basic biological sciences to the clinic and back (e.g. **Cacucci**, enrolled in UCL DClinPsy doctorate to forge links with NHS partners). This is augmented by cross-institutional domains which bring clinical and non-clinical researchers together, and the UCL Academic Careers Office (ACO), which brought in £9.2M in grant funding in 2018/19. It promotes and supports the development of academic and clinical academics working in translational science through a range of programmes designed to enable them to thrive in a research environment. Highlights include the *ADAPT to Thrive* series, in which researchers

share stories of failures from their career (*Festival of Failure*), aiming to normalise failure and build a more resilient research community. Other schemes include *Eureka@UCL*, focused on training in translational research, and *Clinician Coders*, which helps clinical academics to develop skills in data science. As well as offering career and support development, the ACO obtains funding to enable various fellowships (including MRC Skills Development Fellowships and the WT Clinical PhD programme) to be offered through the UCL Clinical Academic Training centre.

**Technical support staff**
A review of core facilities established that provision of expert technical support within our facilities is only possible if we can offer staff secure positions with good career development prospects. Consequently, we are signatories of the national technician commitment (https://www.technicians.org.uk/technician-commitment), and all technicians within research core facilities on short term, usually grant-funded, contracts have been moved onto permanent University funded positions. We now have a cohort of over 40 highly skilled research technicians supporting our research endeavour. We also recognise the challenges that have traditionally faced technicians in terms of promotion and career progression and have an ongoing programme tasked with transforming professional development opportunities for our technical staff. Our goal is to have a technical careers framework comparable to that for our research, academic and teaching staff in place in the near future.

**2.6 Research students**
In total, 1189 postgraduate research (PGR) students were enrolled across our PhD (895) and MRes (294) programmes in the REF period. Yearly MRes recruitment has increased by 8% from 160 in 2013/4 to 172 in 2019/20. Postgraduate Research Experience Survey first destination data highlight the demand for our PhD students. 93.5% went on to graduate level employment, and 2.2% to further study, and the average starting salary was £35K. For MRes students 2016/2017, 50% went on to full- or part-time employment, with an average starting salary of £24K, and 43% are enrolled in further study.

**2.6.1 Current programmes**
Our programmes provide world-class doctoral training through three types of funded programme: broad programmes (typically UKRI) attracting students across different biological science disciplines; focused programmes supporting a particular discipline or institute; studentships through industry/third sector collaboration; self-funded/overseas scholarships. Almost all students undertake four-year PhD programmes, with some starting their project immediately (e.g., iCASE), but most students have rotations during the first 9-12 months that give them a breadth of experience of different research laboratories and allow informed choice of project. Students have direct influence on the delivery of individual PhD programmes through representation on committees/boards. All PhD students are also affiliated to a department, but cohort and inter-cohort activities provide programme identity. These include scientific retreats, bespoke training and employability seminars with a distinct emphasis on student-led and peer-peer engagement.

**UKRI-BBSRC London Interdisciplinary Doctoral Training Partnership (LIDo DTP):**
UCL has led LIDo, the largest BBSRC DTP in the UK with 230 current students (£4M/annum), since its inception in 2012. LIDo was the top ranked proposal in the last two BBSRC DTP commissioning rounds (2014 and 2019) and serves as hub for doctoral training across London. LIDo aims for all PhD projects to have interdisciplinary co-supervision and a large fraction of projects are inter-institutional. LIDo has 8 HEI partners (including Birkbeck) and around 40 iCASE industry collaborators. For impact, LIDo also has Associate Partners: Unilever (the company's only partner in doctoral training), two non-ministerial government departments (FSA and APHA) focussed on food safety and sustainability, and Kew focussed on biodiversity.

**The Birkbeck-UCL MRC PhD programme:** This is the largest MRC-DTP in the UK. The programme started in 2015 and funds 122 students structured across four major streams (Fundamental Mechanisms of Disease, Neuroscience and Mental Health, Experimental and

Personalised Medicine, and People, Population and Data) on 4-year studentships, National Productivity Investment Fund studentships and MRC iCASE studentships. The latter are based on joint projects between academics and large (e.g., GSK, AstraZeneca, Waters, etc) or small-medium enterprises.

**The London NERC Doctoral Training Partnership (including Birkbeck and IoZ):** This UCL-led programme of 8 HEIs, which includes the IoZ, delivers transformative interdisciplinary training in environmental science research and is one of the largest UK NERC partnerships (25-35 studentships per annum). In particular, it supports studentships in biodiversity, evolutionary biology, genetics and disease. It brings together multiple collaborative partners for student internships drawn from business, NGOs, charities, research organisations and government (e.g., Thames Estuary Partnership, UNEP, Defra, POST), with specific funding for entrepreneurship and research experience placements for Summer Studentships.

**CASE Studentships:** We engage with SMEs, government and third-sector through co-funded studentships with about 60 CASE projects active. This relationship is facilitated by an Employability and Placements Officer who oversees fully funded internships for PhD students (BBSRC PIPS) and recent PhD graduates through Flexible Talent Mobility Awards. Contacts to industry are also maintained though PhD programme memberships in networking organisations (e.g., OneNucleus).

**Wellcome 4-year PhD programmes:** Over the REF period, we have held Neuroscience; Structural, Computational and Chemical Biology; Developmental and Stem Cell Biology; and Clinical programmes. The recently awarded Optical Biology programme (2020) brings together neuroscientists, cell biologists, physicists, chemists and computational scientists, with world-leading industrial and academic partners, to deliver training in optical methods, analysis tools and development of new optical technology.

**Partnership for Sustainable Food Future CDT:** UCL is a major partner in a new £5M UKRI Strategic Priorities Fund CDT focused on developing the next generation of interdisciplinary food systems researchers.

**SWC 4-year PhD Programme:** The SWC programme trains up to 24 students in highly interdisciplinary experimental and theoretical neuroscience. The first year is centred around courses taught by SWC and GCNU staff (Boot Camp, Systems Neuroscience and Theoretical Neuroscience, Experimental Neuroscience, Neural Data Modelling) as well as research rotations.

**Gatsby 4-year PhD Programme:** Students study toward a PhD in either machine learning or computational and theoretical neuroscience. The first year consists of intensive instruction in techniques and research in theoretical and systems neuroscience and machine learning before a research project is chosen.

**Institute of Zoology (IoZ) programmes:** As an independent research institution it does not award postgraduate degrees, so all students have a university registration and both university and IoZ supervisors, giving access to expertise and resources across institutions. For IoZ graduating students over the REF period, 34% (27/84) were co-supervised with UCL, more than any other university, and 26% (22/84) involved CASE studentships. IoZ currently hosts 75 students in the £93K Student Hub which opened in 2017 to provide communal workspace.

**The MRC LMCB 4-year PhD programme:** This programme offer students (six per year) three rotations in different LMCB labs with the opportunity of an additional placement at partner Institutes at UCSF or Hokkaido University. Students then undertake their PhD project within the LMCB with full access to all the normal support provided to UCL students. In addition, they attend the annual meeting of the BSCB/BSDB, along with cohort specific training events.

**Crick PhD Programme:** There are 200 Crick PhD students at various stages of their four-year programme at any one time. All students are registered in UoA5 and must have a UCL co-supervisor (with the majority in UoA5).

**SysMIC:** We are the national leaders in the delivery of online training in mathematical, computational and statistical approaches for biosciences students through SysMIC (http://sysmic.ac.uk). This BBSRC and MRC supported programme was developed by UoA5 UCL and Birkbeck staff (with Edinburgh and Open Universities) and recently absorbed a surge in national demand for research skills training during the COVID-19 pandemic providing remote learning for 400 students over 6 months (in addition to >1000 prior students).

**Overseas partnerships:** We have specific partnerships with Bogue Fellowships (to the USA), the Yale Collaborative Student Exchange Programme and A*STAR Singapore PhD programmes. We are also members of EU Innovative Training Networks (e.g., **Bianco** and **Dreosti** lead network in computational and experimental approaches to understanding circuit function in zebrafish).

**MRes programmes:** We host >15 diverse MRes streams across the spectrum of biological sciences, each attracting 5-15 students per annum. Students spend at least nine months on a major research project, and this emphasis on research training provides strong recruitment to PhD programmes.

**2.6.2 Recruitment, supervision and training**

We aim to recruit the highest calibre graduate students, so employ selection processes that are criteria-based with decisions taken by expert panels. Programmes are extremely competitive, with on average 6-8 applications per place. Students choose a principal supervisor and are allocated subsidiary supervisor(s) with specific expertise in parts of the research being undertaken. All supervisors are required to attend the Introduction to Research Supervision course on PhD supervision and must act as a subsidiary supervisor before progressing to primary supervisor. There is also training to enhance supervision (e.g., Building Trust and Examining Doctorates courses). Students complete a minimum of ten training days per year in activities that complement their research, expand their horizon and prepare them for the global job market. These include training in mathematical modelling, analytical, statistical and quantitative skills (e.g., SysMIC); entrepreneurship modules which cover the impact agenda, engagement with business, how to become entrepreneurs and commercialise research, and how environmental science can influence national and international policy (e.g., The Bio-Industry course; Conception X); science communication and media training (e.g. Podcasting for Researchers, Working with the Media, The Guardian Data Visualisation Training); wellbeing (e.g. ADAPT programme run by the UCL Academic Career Office); and research culture (e.g. workshops organised by UKRIO, ReproducibiliTea). There are also 250 courses aligned to the Vitae Researcher Development Framework (RDF) collectively organised by the Bloomsbury Postgraduate Skills Network (an alliance of nine central London institutions designed to expand provision of skills training).

**2.6.3 Integration into the research culture**

Student representatives participate on departmental committees and departments host student-specific seminar series and arrange meetings with external seminar speakers. All students attend annual Departmental Student Conferences, at which a selection of PhD students (across all years of study) give presentations, with awards given to the best talks. Students are also encouraged to engage with UCL Innovation & Enterprise, local networks (https://inno-forum.org), national competitions, in the launch of start-ups (https://www.boobybiome.com, https://www.bento.bio) and SPERO (Santander PhD Entrepreneurship Opportunity). BBSRC LIDo students are required, and MRC-DTP students are encouraged, to organise fully-funded placements in industry, governmental departments, other academic institutions, funding agencies or non-governmental organisations.

**2.6.4 Progress monitoring**

All research students are supported by the UCL Doctoral or Birkbeck Graduate Schools which monitor student progress using an online Research Student Log. Milestones (literature review, progress reports) are monitored by a Thesis Committee. Each UoA5 department/institute has at least one Graduate Tutor (DGT) responsible for ensuring fair and equitable student recruitment, high quality supervision, progress from MPhil to PhD registration, thesis submission; and provide general support. Upgrade from MPhil/PhD to PhD is expected after 9-12 months. For final-year PhD students, we have developed the "Pathway to Completion" programme which includes "meet the examiner" and "know your exam" events, a compulsory residential thesis writing bootcamp, and a leaver showcase. Special systems have also been established to support clinician (often part-time) PhD students, including scrutiny of work plans to help ensure candidates allocate adequate time to their doctoral studies. Of all full-time PhD students starting their degrees in 2013/14, 81% completed their doctorates within the prescribed period.

**2.6.5 Additional COVID-19 specific support for research students**

The pandemic and temporary closure of non-essential research facilities and laboratories in March 2020 created major challenges for PhD students. Several measures were rapidly implemented to ensure continuity of supervision, support, training, and funding. These included: (i) funding to enable students to adapt to home working (e.g. desks, chairs, laptops) (ii) 200 places for online training (using SysMIC materials) to help students develop computational aspects of their projects and remain productive; (ii) UCL & Birkbeck Stipend Extension Schemes to support final-year students, not eligible for Wellcome or UKRI funded final-year extensions, at the minimum London UKRI rate for 3-6 months (iii) allocation of additional UKRI and institutional funds to extend earlier years where hardship or difficulty has been identified, e.g., all requests from 2nd and 3rd year LIDo students have been evaluated by staff across institutions and funded as appropriate, with departments/supervisors also able to top-up stipend extensions; (iv) implementation of multi-level pastoral support to help the sizeable proportion of students who experienced difficulties adjusting or mental health issues as a result of the disruption.

**2.7 Promoting a positive working environment**

Central facilities available to all staff and students include Occupational Health, the Disability Resource Centre and the Counselling Service. To ensure we are aware of staff concerns, and to assist in the design of support mechanisms, UCL undertook staff surveys in 2015 and 2017. Detailed Action Plans were created and implemented following both surveys. This includes the 'Full Stop' campaign and a Dignity at Work policy at UCL to reduce incidences of bullying and harassment. Birkbeck also introduced a Dignity at Work and Study policy in 2017. Specialist Dignity at Work advisors are now available for students and staff to speak to; there is a 'Report and Support' system where incidents of bullying and harassment can be reported directly, or anonymously, or as a 'witness'; and the staff mental health and wellbeing plan, first launched in 2017, aims to improve the psychological health and wellbeing of our staff community (https://www.ucl.ac.uk/human-resources/health-wellbeing/being-well-ucl/get-involved/staff-mental-health-and-wellbeing-plan).

**2.8 Equality, Diversity and Inclusion (EDI)**

UoA5 research staff are 38.5% female, ethnically diverse (14% BAME), and international (35% EU, 25% non-EU); 2% have a disability and 3% declare as LGBT+. We continue to place great emphasis on initiatives that cover Disability, Gender, LGBTQ+, Race and Religion & Belief because diversity enhances the academic environment, broadens perspective and increases the talent pool of our staff.

- The Athena SWAN (AS) scheme has been the main foundation for our policies and initiatives on EDI. AS Self-Assessment Teams have been established in all departments/institutes and are represented on the senior leadership teams. Departments/institutes within this submission have obtained nine AS awards during the REF period, and in addition UCL and Birkbeck hold Silver and Bronze institutional awards. At the departmental level within UoA5 we hold Gold (LMCB), Silver (Birkbeck Biological Sciences) and Bronze (IoZ, SMB, CDB, NPP and GEE) awards.

- All departments/institutes within UoA5 have an EDI action plan for staff and students and these inform targets for senior leaders set in their appraisals. There are EDI champions, central teams of EDI managers and advisors, and Vice/Assistant Deans for EDI and for Race, Gender Equality and Disability have been appointed at UCL (**de Bruin**) and Birkbeck (**Thompson**). Our staff have served on institutional and national EDI committees and networks including: the Disability Equality Steering Group, Enable@UCL (for staff with disabilities), Neurodivergent Staff Network, Parents and Carers Together, Out@UCL, Friends of Out@UCL, LGBTQ+ Equality Advisory Group, RaceMatters@UCL, Race Equality Steering Group, Gender Equality Working Group, UCL Menopause Network and a Male Allies Group (the men are allies to gender equality/women).
- *Unconscious Bias* training is mandatory at UCL and Birkbeck and is now embedded into the induction process. In 2018/19, 27 staff completed UCL's *Taking The Lead* training, equipping them with the skills to address bullying and harassment, and ten *Where Do You Draw The Line* workshops have been held (attended by >150 staff), a harassment prevention approach collaboratively developed by UCL, Cambridge, Manchester and Oxford.
- Staff have generous maternity and paternity leave entitlements, options of career breaks and/or flexible working, family-friendly and flexible working practices (e.g., meetings in core working hours, and respect for parental child caring duties).
- The LIDo DTP has created a Research Experience Placements (REPs) programme to target under-represented minorities with summer studentships. This initiative attracts industry sponsorship and has been supplemented with 'the Pathway to PhD' summer event to encourage and advise BAME students in the development of high-quality PhD applications.
- We designed a rigorous system for REF 2021 output review and selection to ensure best EDI practice was observed. Two independent internal scores were solicited for each output by a large and diverse group of referees (154 staff, 43% male, 57% female) across all contributing departments. Staff involved in preparing the final output submission attended face-to-face REF-specific EDI training in addition to mandatory 'Diversity in the Workplace' training. The initial draft of the final selection of outputs was performed by an algorithm that maximises the Unit score and is blind to gender or other protected characteristics, career stage or subject area.

Comparisons between REF periods provides evidence that our initiatives are bringing about change. Highlights include:

- 29% of the 548 attributions in our 2021 output submission are from female scientists, reflecting the distribution of eligible staff (30% female). Importantly, 51% of the early career, independently funded, attributions are from female scientists, again reflecting their distribution (48% female).
- We have seen increasing representation of women in leadership roles. 5/10 Heads of Research Department/Institute are now women (0/5 in REF 2014).
- The number of female staff in senior positions (grade 10) has risen (from 19% to 25% over the REF period).
- At least 8 female staff who attended institutional Leadership programmes are now in senior leadership positions (e.g., **Djordjevic** (now Head of SMB), **Jones** (UCL East Nature Smart lead), **Sumner** (Divisional Athena SWAN lead), **Townsend-Nicholson** (SLMS Knowledge Transfer & Enterprise Champion).
- The number of female staff in junior positions (Grade 7 and 8) remains high (43%). Female staff have also been 33% more likely to receive junior promotions than male colleagues.

- Birkbeck & UCL are Stonewall Diversity Champions. UCL was named as one of the UK's best employers for lesbian, gay, bi and trans staff in the Stonewall 2018 Top 100 Employers Index (ranked 98th out of the 434 employers).
- UCL is a Bronze Award holder and Birkbeck a member of the Race Equality Charter
- **Sumner**, British Ecological Society Equality & Diversity award (2016); **Cramer**, Athena Prize, Top Individual Award (2019).
- The LIDo DTP was the only DTP cited by UKRI for innovative inclusive practises in response to an open letter from minority academics about BAME PhD student opportunities (Research Fortnight 2020).

**2.9 Future actions to create and promote an inclusive environment based on data analysis**

**Increasing the number of women in grade 9 and grade 10 positions:** The number of female staff in grade 9 and 10 (27% in 2020, 25% in 2013) or grade 7 and 8 (44%, in 2020, 47% in 2013) is similar across REF periods. This illustrates that fewer female staff still reach senior positions. This does not appear to be due to gender bias in the promotion decision as of the 83 senior academic promotion applications since 2014, female staff were just as likely as men to be successful. This suggests (a) junior female staff do not apply for promotion, (b) there are factors influencing the success of junior female staff or (c) bias in external recruitment to senior posts. To address these issues (a) department/institute heads have been tasked with ensuring that female members of staff are encouraged to apply for promotion, with mandatory discussion about preparation for promotion during appraisal; (b) we have introduced mentoring schemes, career development seminars for early career scientists, and talks from women scientists working in policy, industry and academia. Seminar organisers have been tasked with ensuring a 50:50 gender balance to ensure visibility of leading female researchers; (c) shortlisting and interview panels must now be balanced in gender, with one panel member tasked with ensuring unconscious bias does not affect decisions about female applicants.

**Increasing BAME representation at all grades:** The proportion of BAME staff in the unit remains unchanged from 2014 at ~15%. This under-representation is even greater at grade 9/10 (10%) than at grade 7/8 (19%). To address these issues, researchers in this unit have set up a Racial Equity Committee who have worked with HR to update hiring procedures to reduce bias and discrimination. There is a webpage to communicate ongoing activities, provide opportunities for volunteering and create a set of educational resources related to racial equity. The Fair Recruitment Specialist initiative has been established to train twenty existing BAME staff to act as advisers and promote visible diversity during recruitment, and we aim for every hiring committee to use a fair recruitment process specialist from autumn 2021. Seminar organisers have been tasked with ensuring diversity amongst speakers. An annual survey related to EDI will be trialled to allow progress to be tracked.

**3. Income, infrastructure and facilities**

Despite this being a challenging REF period in provision of funding for basic biosciences research, research grant income to UoA5 researchers rose to £479M. This represents £68.5M/year (compared to £33.4M/year in REF 2014) and £312K/FTE/year (compared to £176K/FTE/year in REF 2014). The >1.75-fold increase reflects the success of our research strategy, with income from diverse sources. This includes £125M from UKRI (e.g., BBSRC (>£32M), MRC (>£67M), other RCUK (£25M, e.g., NERC, EPSRC)), Wellcome (£138M), EU (£42M), and industry (£6M). We have been supported by prestigious awards including 3 Wellcome PRFs, 22 Investigator Awards, 4 Collaborative Awards, 7 SRFs; 2 BBRSC sLoLa; 2 ERC Advanced and 5 Consolidator Awards, 5 MRC Programme Grants. We have been awarded 25 senior ECR fellowships worth in excess of £23M, including 3 MRC, 12 Wellcome SHD, 6 ERC Starter and 5 Royal Society URFs. Junior fellowship awards include 12 Sir Henry Wellcome and 36 Marie Skłodowska-Curie.

### 3.1 Strategies for research income generation

Institutional-level resources and initiatives are described in REF5a. At UoA5 level, research strategy is developed and implemented by a senior executive team comprising Institute/Division Directors, the Vice-Deans for Research and Enterprise, and others with key roles. Regular meetings with Heads of Departments ensure alignment with departmental strategy. Departments and Institutes provide support for PIs (e.g., mentoring, internal grant peer review, away days). UCL has also invested in the cross-Faculty Research Coordination Office and Translational Research Office. They each comprise a team of >15 senior academically trained personnel, often with a background in the research funding or commercial sectors. They have been instrumental in the strategic review of facilities (see **3.2**), coordinating major funding applications involving multiple labs or institutions (together with Domains); supporting research initiatives that cut across different disciplines; organizing grant writing workshops and mock interviews; administering internal funding schemes. Similarly, the European Research & Innovation Office provides advice about EC programmes and promotes interaction with other EU groups.

### 3.2 Facilities, equipment and technical support

#### 3.2.1 Funding sources

The best research facilities need cutting-edge space and equipment, and highly skilled technical support. Institutional investment has come through Capital Infrastructure Funds (>£5M), and the Capital Equipment Fund (CEF) which was established in 2018 (total funding £10.6M and >£6.5M of CEF has supported research activity within UoA5). The LMCB also received £24M from the MRC and the SWC received >£120M from Wellcome and Gatsby Foundation in core support. We have also secured £10.6M in awards from Wellcome and BBSRC shared equipment schemes; £0.5M from Wellcome ISSF and on average £1.7M in institutional funding per year has been used to provide matched funding for equipment requested on grants.

#### 3.2.2 Funding prioritisation

All applications for shared equipment (internal or external funding) receive rigorous internal review through panels led by the Chair of our cross-Faculty Research Board and four Vice-Deans for Research. This ensures priority is given to cross-Faculty and multidisciplinary and multi-institution applications and that we only submit highly competitive, well-coordinated and strategically important applications to external calls.

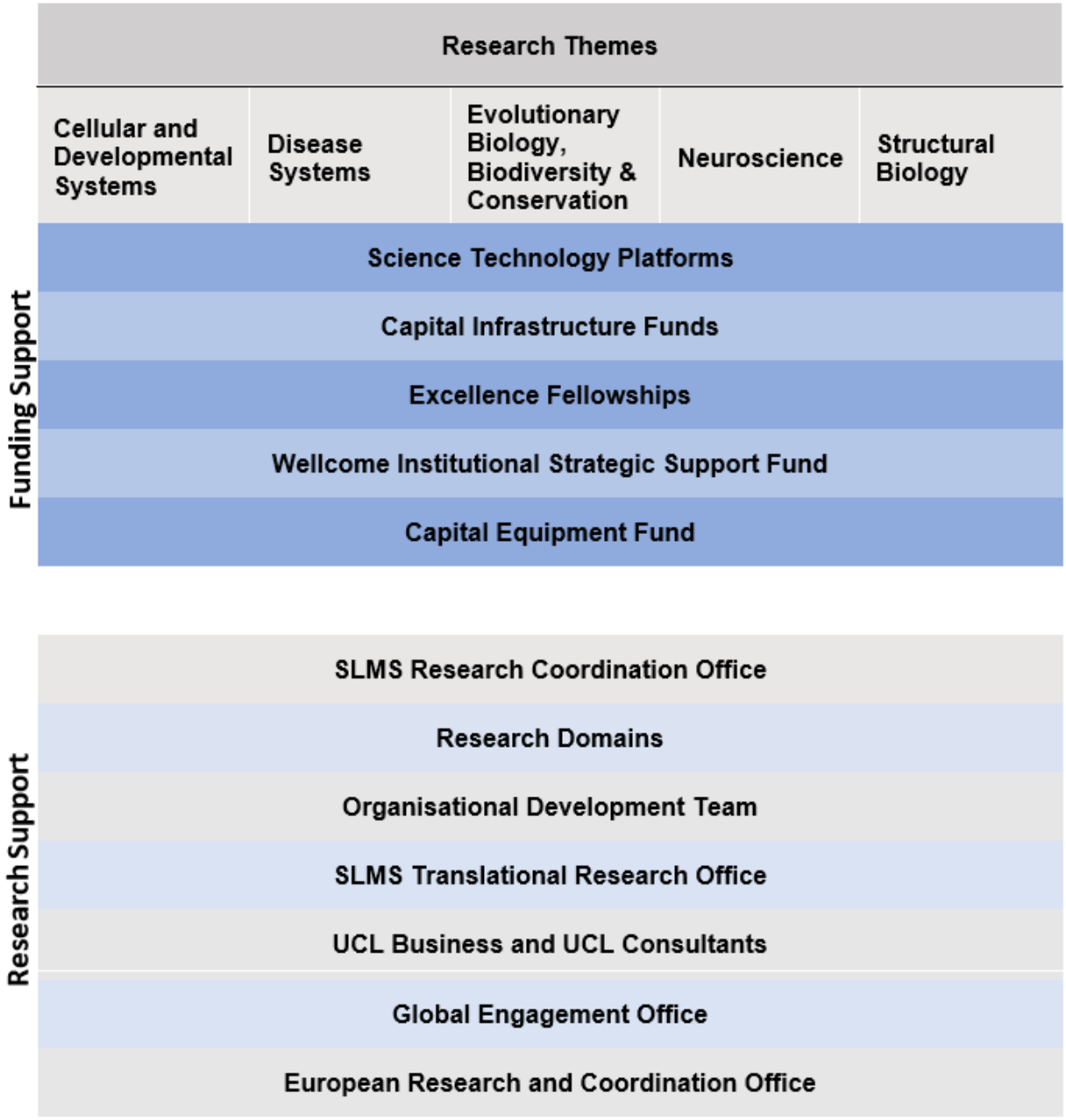


*Figure 2. Cross-cutting support structures that facilitate interdisciplinary research and procurement of grant, industry and translational funding.*

**3.2.3 Science Technology Platforms (STPs)**

During the assessment period, we reviewed all research facilities that support UoA5 research. This review concluded that although some facilities are best suited to support research activity in their local environment, the function and availability of others is most effective when centralised, enabling the sharing of expensive equipment and technical expertise. This resulted in a major programme of work to consolidate small facilities, revamp space and equipment and ensure the provision of appropriate technical expertise under the framework of Science Technology Platforms (STPs). STPs have academic and technical leadership who provide strategic oversight of the services offered, its equipment and its technical support needs, and ensure a coherent and consistent service. In 2020 eight new STPs were launched, with four led by UOA5 researchers: Genomics and Sequencing; NMR Spectroscopy (**Christodoulou**); Mass Spectrometry (**Thalassinos**); Biological Services; Imaging (**Pichaud**); Fish Facility (**Wilson and Bianco**); Radiochemistry; Cell Sorting. STPs are subject to rigorous annual review and

accountability, after which strategic goals are prioritised for capital funding. Investments in the UoA5 led STPs are described in more detail below.

**Imaging STP**
The light and electron microscopy STP has brought together existing and new facilities to provide researchers with access to a wide range of cutting-edge wide-field, confocal, multi-photon, light-sheet, super-resolution imaging and scanning, transmission and cryo-electron microscopy.

*UCL-Zeiss Multi-Scale Imaging Centre (UZMIC):* This new (completed in 2019) advanced imaging centre is dedicated to dynamic imaging across scales, from single molecule resolution to organelles, cells and tissues, and from a single sample to high throughput analysis. UCL invested ~£2M to provide purpose-designed, fully renovated and refurbished space, in addition to a contribution of approximately £1.5M from Zeiss. Microscopy equipment includes a Zeiss Light Sheet Z1 and Zeiss LSM 800 confocal microscope allowing for low phototoxicity imaging of living cells at super resolution (BBSRC and UCL CEF £460K), Scanning Tomography arrays electron microscope (Wellcome MUE award £550k), Zeiss 880 Airyscan systems, one with UV optics and full spectral detection (UCL CEF £750K), Zeiss Airyscan 980 Fast II 8-Y upright microscope with multiphoton laser and Zeiss Elyra 7 Lattice SIM super res (UCL CEF £680K), Zeiss Airyscan 980 Fast II 8-Y, inverted microscope (UCL CEF £540K), Renishaw Invia Raman confocal microscope (BBSRC and UCL matched funding £430K), Nikon X-Ray CT scanner (UCL CEF £360k) and Leica 3D Fluorescence Stereoscope Thunder system (UCL CEF £65K).

*Super-resolution and other advanced imaging*: The SuRF super-resolution imaging facility spearheaded by UCL/Birkbeck was set up in 2013/14, in part through a £1.6M grant from the MRC. It has applications which span multiple UoAs (e.g., cell biology, physics of biological nanomachines, biochemical engineering of therapeutic proteins, chemistry of synthetic biomimetic molecules). It now includes three microscopes that are optimized for cell imaging: TIRF STORM system, Structure Illumination Microscope equipped for PALM, 2-colour STED recently upgraded in 2018 with a second depletion laser (UCL CEF ~£150K). This has been further enhanced by a 3i Lattice Light Sheet microscope allowing for low phototoxicity imaging of living cells at super resolution (BBSRC £500K 2017). In 2020, SuRF installed the UK's first microfluidic enabled benchtop, turn-key, multi-function super-resolution microscope from ONI (BBSRC £200k) to enable research on in vitro reconstituted molecular machines and further simplify access to these technologies to non-specialist/traditional users. As part of SuRF, two new optical development laboratories (led by **Henriques** and **Lowe** and supported by the recruitment of senior grade 9 expert tech support) have been established (£300K refurbishment) to develop new methods of super-resolution imaging and data analysis. They are light and vibration isolated; and pressure, energy and temperature controlled, with a dedicated fibre-optic network connection to a CPU and GPU farm capable of high-performance computing on the generated data. In addition, 3i engineers have bench space, where they collaborate to develop new technologies. The lab pioneered the development of the sulfoscope, a microscope capable of imaging Hyperthermophilic Archaeon (**Baum,** Curr Biol 2020, Science 2020) and has developed new quantitative technologies to improve Super-Resolution Imaging (**Henriques,** Nat Meth 2018; Nature Comm 2019).

*Electron microscopy and cryo EM:* The emergence of new EM technologies has revolutionised biology. To capitalise, this REF period has seen significant investment in these technologies. This includes a ZEISS scanning electron microscope for array tomography (Wellcome (£333K) and UCL (£150K)). Together with an associated light microscope, it allows novel 3D ultrastructural imaging and is the first correlative workflow of its kind in the UK. We have also added a state-of-the-art 300kV Krios electron microscope (installed in 2018 with £4M Birkbeck/UCL/Wellcome funding) equipped with Direct Electron Detectors (K3 and Falcon III detectors), a phase plate and energy filter. Single particle and cellular tomography are fully supported as well as correlative cryo fluorescence/EM microscopy. Vitrobot and Leica GP2 cryo plungers are available for sample preparation. Cell preparation equipment includes a high-pressure freezer, cryo microtome and freeze substitution and a cell culture suite. The lab is run

by two full-time research support posts (EM technical manager and scientific facility coordinator), and departmental IT staff manage high-performance computing resources needed for these experiments.

**Fish Facility STP**
The UCL Fish Facility is a state-of-the-art resource that provides researchers (including other HEIs and Research Institutes) with access to several hundred genetically distinct zebrafish lines. It is run by a senior manager and 7 core staff, and investment of over £1.5M during the assessment period has more than doubled space/capacity, enabling a much broader range of research programmes including ambitious forward and reverse genetic screens. This investment has also allowed us to recruit ECRs in UoA5 (**Bianco, Dreosti**) and other UoAs (Macdonald, Young and Tuschl). The Facility also maintains cavefish (**Yamamoto**) and has recently established a killifish facility to support research in cancer and healthy ageing (Payne, **Bahler**). Most technicians working in the Facility participate in research activities, present at conferences, and publish their work. This has paid particular dividend during the pandemic as facility staff have taken on active roles in supporting research.

**NMR and Mass Spectrometry STPs**
These STPs provide fully supported access to a wide range of biophysical instrumentation including UV-Visible, fluorescence and CD spectroscopies, robot-assisted screening, DLS, DSF, ITC, DSC, BLI and SEC-MALS instruments. Equipment is housed in a purposed designed lab space refurbished in 2020 with Wellcome/Birkbeck/UCL funding (£300K) with dedicated space for sample preparation. It also houses 500, 600 700 & 800 MHz Spectrometers. The higher field instruments are focussed on structural determination and are all equipped with cryogenic probes. The 500 MHz Bruker Avance II system is equipped with automated sample changer and cooled probe for medium throughput screening (e.g., in metabolomics) and quality control of protein samples. The MS facility performs ion mobility and protein conformational studies on isolated proteins/complexes using a Waters Cyclic Ion Mobility Mass Spectrometer and basic protein identification using QTOF technology. Computational tools are also developed for data analysis.

**3.2.4 Other support for UoA5 research**
Researchers have access to standard molecular biology, biochemistry, tissue culture and microbiology equipment, next-gen and Sanger sequencing, genotyping services. A wide range of biophysical and crystallographic instrumentation is available at the ISMB BiophysX Centre, including UV-Visible, fluorescence and CD spectroscopies, DLS, DSF, ITC, DSC, BLI and SEC-MALS instruments. Equipment is housed in a purposed designed lab space refurbished in 2020 with Wellcome/Birkbeck/UCL funding (£300K) with dedicated space for sample preparation, robot-assisted screening and X-Ray system for in-house crystallography. UoA5 researchers also received £951K in-kind benefits to use shared UKRI facilities such as the Diamond Light Source (£247K) and European Synchrotron Research Facility (£354K). There is also substantial access to the national Electron Bio-Imaging Centre (eBIC) at Diamond. **Saibil** was co-lead on the £15.6M grant from Wellcome/MRC/BBSRC that established eBIC in 2015 and is currently a member of the Executive Committee. Finally, UoA5 researchers have access to 16 UCL libraries whose staff support Open Research through administration of the REF OA policy and UCL Discovery, UCL's Open Access Repository.

**3.3 Research governance**
Research governance policies that underpin expectations about the conduct of research are detailed in REF5a. These include principles and training in research integrity, and initiatives to prevent misconduct and define action to be taken in the event that an individual is suspected or accused of research misconduct. All issues relating to confidentiality and security in the use of patient and participant data fall under UCL's Data Protection policies and the Data Protection Office provides extensive training, guidance, and support.

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

Our goal is to foster a rich environment where collaborative and interdisciplinary research is the norm, and where our researchers provide essential contributions to the research base, economy, society and the vibrancy of the wider scientific community. Data evidencing these activities were obtained from a comprehensive survey completed by ~90% of submitted UoA5 staff.

**4.1 Major institutional collaborations**

Francis Crick Institute: We are a founding member (£40M investment) and UCL provides direct financial support (>£1M/annum) for over 80 UCL researchers physically located in the FCI. During the assessment period, our unit has made major joint strategic appointments (e.g., **Luscombe, Goering, Schaefer**), seconded entire research groups (e.g., **Tedesco**) and established satellite research groups (e.g., **Szabadkai, Henriques**) as part of our Crick-HEI Attachment Scheme. UoA5 staff are also supervisors for many students on the Crick PhD programme, and participate in many scientific interest groups and other shared activities.

The Rosalind Franklin Institute: UCL is a founding partner of this national institute dedicated to bringing about transformative changes in life science through interdisciplinary research and technology development. The research synergy has seen UCL appoint researchers to lead the University's work in RFI research themes of Biological Mass Spectrometry (**Thalassinos**) and Structural Biology (**Werner**).

The Natural History Museum: UoA5 researchers are embedded in this partnership through collaborative research (e.g., Goswami, **Day**), gaining access to its unique research collections, and several NHM staff are involved in research collaborations at UCL where they hold honorary Professorships (e.g., Knapp, Lister).

Royal Veterinary College (RVC): IoZ has collaborated with the RVC for over 20 years delivering novel MSc/MSci programmes on wild animal health and wild animal biology which are strategically important for conservation scientist training. The RVC, together with UCL, is also a partner in the proposed National Institute for Biodiversity and Public Health (described above).

**4.2 Individual collaborations**

UoA staff have been involved in extensive collaborative and interdisciplinary research. Collaborations involve both UK (71% of staff) and international (84% of staff) institutions, with 61% defined as interdisciplinary. This has resulted in membership of 53 European research networks (€31M UoA5 funding out of €73M total awards), 4 Wellcome Collaborative Awards (£6.7M) and 2 BBSRC sLoLa (£1.5M share). 48 members of staff (24%) have hosted visiting international researchers, many funded by competitive schemes. Collaborative interdisciplinary working is also promoted by joint appointments and the award of honorary positions (including Category C staff). A total of 275 individuals held such positions on the census date, with 86 at professorial level.

**4.3 Contribution to the research base**

The breadth of contributions is highlighted by the following aggregate metrics:

- 41% of staff have served on national or international grants committees, and 71% on learned societies/professional bodies/international research committees ;
- 57% of staff have given invited keynote lectures;
- 61% have participated in conference organization;
- 87% have examined doctorates;
- 51% of staff served on journal editorial boards, 27% in editorship positions;
- 97% engage as 'good citizens' and are involved is some aspect of refereeing/peer-reviewing. Most exceed these minimal expectations;
- 41% served on committees of national funding agencies including research councils and major Charities and other international funding bodies.

Prizes such as scholarly fellowships or related awards have been awarded to 52% of staff and provide a metric by which the contribution of individuals is recognised. Major honours/prizes awarded to both early career and senior researchers include:

Early career:
L'Oréal for Women in Science Fellowship 2016, 2020 (**Acton, Mao**)
Lister Institute Research Prize 2014, 2018 (**Boucrot, Mao**)
BSCB Women in Cell Biology Early Career Medal 2020 (**Mao**)
EMBO YIP (**Cheung, Dessimoz, Mao, Roberts**)
Medical Research Foundation Emerging Leaders Prize, 2020 (**Fabrizi)**
Biochemical Society Early Research Career Award, 2015 (**Roberts**)

Senior:
Fellows of Royal Society (**Orengo, Silver, Fitzgerald, Dolphin, Hausser**)
Fellows Academy Medical Sciences (**Brodsky, Lloyd**)
Members of EMBO (**O'Keefe, Margrie, Paluch, Mayor, Orengo)**
Biological Secretary of Royal Society (**Partridge**)
Biochemical Society Award, 2015 (**Lane**)
ZSL Silver Medal, 2015 (**Pettorelli**), 2016 (**Sumner**)
Member of the British Empire (MBE) for Services to Higher Education and Culture, 2015 (**Chatterjee**)
Fondation Ipsen Prize for Neuroenergetics, 2016 (**Attwell**)
Zoological Medal, the Linnaean Society of London, 2016 (**Mace**)
Royal Society Faraday Prize and Lecture, 2016 (**Lane**)
Royal Society Croonian Lecturer 2017 (**Ashmore**)
Ross G Harrison medal, International Society for Developmental Biology, 2017 (**Stern**)
Distinguished Career Award, International Association for the Study of Pain 2017 (**Fitzgerald**)
Zoological Society of London's Scientific Medal 2018 (**Pearson**)
Charles L Hoppel International Prize 2018 (**Duchen**)
AHRC-Wellcome Health Humanities Medal 2018, (**Chatterjee**)
Membership of the Norwegian Academy of Science and Letters (2018) (**Attwell**)
Presidential Lecture, International Society for Cerebral Blood Flow and Metabolism, 2019 (**Attwell**)
Linnean Medal for Zoology 2019 (**Turvey**)
Royal Society Wolfson Fellowship 2019 (**Burbano**)
Feldberg Foundation Prize 2020 (**Hausser**)

**4.4 Contribution to research networks and community resources**
UoA5 researchers have established resources and databases that provide the gold standard for research in their field. In structural biology, UCL is one of the 11 institutes that constitute the UK Node of the ELIXIR infrastructure for bioinformatics, the inter-governmental coordinating body funded by national governments and the EU for bioinformatics resources. CATH-GENE3D (**Orengo)** is the major service from UCL. It has become the world standard resource for taxonomic classification of protein structure in terms of functional domains (NAR 2018) and contains domain predictions for 82 million gene sequences presently available in public databases. The Protein Circular Dichroism Database (PCDDB) developed by **Wallace** (NAR 2017), is also part of the ELIXIR landscape and provides the global repository for CD data on proteins, whilst the Intrinsically Disorder Protein ELIXIR Community (F1000 Research 2019) aims to establish standards for data storage and dissemination for disordered proteins. **Martin** (J Mol Biol 2017) has generated abYsis and AbDb for management of structural data on antibody diversity and modelling for therapeutic development (see Impact Case study). Other highlights include: the Living Planet Index, a global dataset of wildlife population trends which is curated by **Freeman**; gold standard resources for model organisms (**Thompson** (*Dictyostelium* mutant resource) and **Bahler** (POMBE base)); databases of gene expression and neuroanatomy in embryos (ECAP; **Stern**; zebrafishbrain; **Wilson**); and The Global Avian Invasions Atlas, a database of alien bird distributions worldwide (**Blackburn**).

**4.5 Contribution to the economy and society via collaboration with government, government agencies, the NHS and industry**

Engagement with industry is encouraged through CASE studentships or industry-sponsored research (46% of staff), or consultancy (15%, £0.5M total). Effective collaboration with industry has resulted in the award of £5.5M in grants from industrial partners, leading to significant translation or commercialisation: 26% of staff have been involved in patents, licensing, spin-out formation, consultancy, clinical trials, or been awarded translational funding and secured UCL Business proof of concept funding (0.6M), Translational Research Office funding (£0.75M). Others work with health and social care services (6%); or with central or local government bodies (10%, £1M). This includes advice to UK Government including Ministers of State, all-party Parliamentary Groups, BEIS, House of Commons/Lords Select Committees and DHSC (e.g., **Chatterjee**, social prescribing; **Jones** UK's future preparedness for pandemics; **Mace,** human impact on the environment). These activities are mirrored internationally through work with global regulatory bodies (e.g., IUCN, United Nations, World Organisation for Animal Health) concerned with infectious and non-infectious disease in wildlife (**Cunningham** and **Garner**), zoonoses (**Cunningham** and **Jones**), human-wildlife conflict (**Durant** and **Woodroffe**), species reintroductions (**Ewen**), and global biodiversity trends (**Mace** and **Freeman**).

**4.6 Response to the COVID-19 pandemic**

Researchers and facilities in UoA5 have made major contributions to the national effort to fight the COVID-19 pandemic. This includes recent evidence to the House of Commons Science and Technology Committee on the UK's prior preparedness for a pandemic based on research into the relationship between infectious disease and habitat loss, biodiversity, bats and live wildlife markets (**Jones**). Before the emergence of the COVID-19 pandemic, work on predicting and modelling Ebola and Lassa fever had led Jones and colleagues to repeatedly warn that environmental degradation around the world was increasing the likelihood of 'spillover' events and pandemics. The recommendation now is that public health organisations, ecologists and conservationists must work together to investigate causes of disease (i.e. spillover from wildlife) as opposed to solely focusing on proximate causes (i.e. human-to-human spreading). Our researchers have also spearheaded COVID-19 studies, including the COVID-19 Mass Spectrometry Coalition, of which **Thalassinos** is a founding member. To date, more than 500 scientists from 18 countries have joined the coalition and are working to use mass spectrometry to identify molecular markers indicative of disease severity. Researchers have also provided insights into viral evolution and transmission (e.g., **Balloux** and **Van Dorp**, Nat Comms 2020; **Orengo**, Sci Reps 2020**; Santini,** Lancet Microbe 2020).

**4.7 Contribution to society via engagement with wider audiences**

Staff in this UoA (79% in total) have interacted with or developed relationships with audiences outside the university sector, including museums, schools, the media, policy makers, patient groups, local communities, and healthcare practitioners.

Highlights include:

*Institute of Zoology:* The unique position of the IoZ, as the research arm of the Zoological Society of London (ZSL), affords the opportunity to engage with >1.4 million people visiting ZSL's London and Whipsnade Zoos annually, including c.150,000 children participating in the ZSL schools programme. IoZ/ZSL also has an annual programme of 10-15 free public science lectures (2000 attendees), 2 international symposia (350 attendees), and 1 early career event (55 attendees). All IoZ staff and students are supported in outreach activities, and to develop innovative public engagement, such as the 2018 online dissection of a dolphin, which has been viewed almost 200,000 times. IoZ also has a strong track record of enlisting citizen scientists, and promoting participation and enabling nationwide projects, such as the Garden Wildlife Health initiative.

*Popular science writing*: UoA5 researchers (e.g., Jones, **Lane**) have written best-selling and prize-winning popular science books, often stemming directly from their own research activity.

Highlights include **Lane**'s *The Vital Question* (2015) for which he was awarded the 2016 Royal Society Michael Faraday Prize.

*Soapbox Science* is an annual global outreach programme that now runs events in public spaces in 14 countries across 5 continents, showcasing women in science and providing inspiring role models to encourage higher participation in STEM. Co-founders **Seirian Sumner** (UCL) and **Nathalie Pettorelli** (IoZ) received a 'Points of Light' award from Prime Minister David Cameron in 2015 for this work.

*Museums and collections*: The location of UCL, Birkbeck and IoZ has enabled collaborative work with The British Museum, British Postal Museum, Central St Martin's Study Collection, Islington Museum, UCL Museums, Petrie Museum, and Tate, as well as Tunbridge Wells Museum & Art Gallery, Canterbury Museums & Galleries, Whitworth Gallery, Spanish Cultural Heritage Institute, and The Royal Danish Academy of Fine Arts. This engagement includes scientific approaches to measuring the benefits of cultural experiences for health and wellbeing (**Chatterjee**), developing museum exhibits (ancient DNA (**Mott**), perceptions of Nature (**Mace**), model organism research (**Bianco**) and the preservation of museum specimens (**Odlyha**).

**4.8 Summary**

This REF period has seen a step change in the environment for UoA5 researchers due to tremendous investment across UCL, Birkbeck and IoZ, together with extensive recruitment at all career stages; the development of a diverse, collaborative and supportive working environment; and provision of cutting-edge facilities, infrastructure and expert technical support. This world-class environment has enabled our researchers to undertake the world-leading interdisciplinary research evidenced in the submitted outputs and impact cases for this REF period and provides a foundation for future success.