

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

1. Overview, Context and Structure

Biological sciences research at the University of Bristol (UoB) is internationally-renowned, matching the University's global reputation (consistently UK top 10 in THE and QS World University rankings). We have a long-standing record of excellence, form the largest concentration of bioscience researchers within the South West of the UK with our research encompassing the full spectrum of the biosciences, from molecules to cells to organisms to ecosystems.

Our vision is to support *creative, investigator-led discovery research*, delivering impacts in the biotechnological and creative industries, in human and animal health, in ecosystem services and conservation of biodiversity. The breadth and depth of our research in UoA5 enables strong interdisciplinary links from environmental and physical sciences (UoAs 7-10) through to medical and clinical research (UoAs 1-6).

We are strongly *committed to equality, diversity and inclusion* (EDI) and to the career development of all our staff including actively supporting early career scientists. *Scientific innovation* is also central to our mission and is fostered through close integration with local business centres such as Unit DX/DY and the global award-winning SETsquared partnership.

Research in this submission takes place across the Schools of Biological Sciences and Biochemistry which, in 2018, were integrated into a *new Faculty of Life Sciences* to better consolidate and support our biosciences research, education and administration. This has brought the Schools and biosciences researchers closer together, accelerating cross-disciplinary research collaborations, major funding applications, and a new strategy focused on building excellence and critical mass in key important challenge areas. The new structure also better complements the health sciences (medicine, dentistry and importantly veterinary), neuroscience and biomedical sciences at the University.

This UoA has also benefitted from the increase from two in 2014 to now *five interdisciplinary University Research Institutes (URIs)*: Cabot Research Institute (Environment), Jean Golding Research Institute (Data), Brigstow Research Institute (Living and Being), Elizabeth Blackwell Institute (EBI) (Health) and the Bristol Digital Futures Institute (REF5a). These Institutes have proven highly effective for UoA5 in accelerating research collaborations, and in developing major funding applications and a new strategy focused on building excellence in emerging fields. The success of this new structure is perhaps best illustrated by the rapid pivoting of UoA5 research (through EBI) in response to the COVID-19 pandemic to produce substantial breakthroughs in under a year (evidenced by two *Science* papers in 2020).

This submission includes the work of 73 staff (70.5 FTE), comprising 62 core-funded staff and 11 Research Fellows, 7 of whom are currently Early Career Researchers (ECRs), and external research funding spend of approximately £81m (see REF4b). In addition, the work of about 300 researchers and 250 doctoral students is represented in the submission.

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Across UoA5, our research spans *six coherent and complementary themes*:

- i. **Ecology, Environmental Change and Evolutionary Biology** (FTE 10.0, ~£7.3m research spend including 1 x European Research Council (ERC) Starter award, 1 x Natural Environment Research Council Independent Research Fellowship (NERC IRF), 2 x Royal Society University Research Fellowships (RS URF)) where research focusses on ecosystem and species responses to different and changing environments in the past, present and future.
- ii. **Behavioural Ecology and Sensory Biology** (FTE 12.0, ~£11.0m research spend, 1 x ERC Adv, 1 x ERC Consolidator, 1 x ERC Starter awards, 1 x NERC IRF, 4 x RS URF) with strategic emphasis on the effects of anthropogenic stressors on organisms and mechanisms of sensory systems linked to innovative bio-informed technologies.
- iii. **Plant and Agricultural Sciences** (FTE 10.3, ~£11.9m research spend, 1 x ERC Starter award, 2 x RS URF) addressing whole organism physiology, diseases and insect vectors that carry plant diseases, and mechanisms linked to plant productivity aligning with the needs of industry.
- iv. **Synthetic Biology** (FTE 9.8, ~£12.5m research spend, including Biotechnology and Biological Sciences Research Council (BBSRC)/Engineering and Physical Sciences Research Council (EPSRC) Centre, Max Planck Centre, 1 x Wellcome Trust Investigator Award in Science (WT SIA), 1 x ERC Adv) with a particular focus on *de novo* protein design and understanding and exploiting molecular assemblies.
- v. **Dynamic Cell Biology** (FTE 14.6, ~£27.4m research spend, 3 x WT SIA, 3 x WT Sir Henry Dale Fellowships (SHDF), 2 x BBSRC Strategic Longer and Larger (sLoLa) grants) addressing intracellular membrane and protein trafficking, cytoskeletal dynamics, and wound healing.
- vi. **Molecular Biosciences** (FTE 13.8, ~£11.4m research spend, 2 x ERC Adv, 3 x WT SIA, 1 x Cancer Research UK Fellowship (CRUK F), 1 x BBSRC David Phillips Fellowship (DPF)) focusing on protein-nucleic acid interactions and the mechanisms of molecular genetics.

Major achievements in the period 2014-2020 include:

- A significant contribution to the advancement of scientific knowledge across the biological sciences. *Over 1500 outputs* have been published in Scopus® Indexed journals with more than 300 of those in the top 10% most highly cited publications.
- The *recruitment of 25 scientific leaders*, 12 of those as ECRs who have become permanent independent scientists.
- The *creation of focused Specialist Research Institutes (SRIs)* with emphasis on specific priority research areas. UoA5 researchers have been central to the establishment of BioDesign SRI, hosting our Synthetic Biology activity, and a Max Planck Centre for Minimal Biology (one of only six outside Germany).
- *Extensive investment in our buildings and infrastructure*, totalling over £70m.
- Continued improvement in our environment for our *commitment to EDI and research culture* recognised by the awards of first Bronze (2014/15), then Silver (2018/19) Athena Swan awards for both Schools in UoA5.
- At an institutional level, an increase to five URIs, driving opportunities for University-wide interdisciplinary collaboration. Biosciences research is at the core of three of these URIs.

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- Acknowledgements of our innovation successes include *prestigious awards* such as the BBSRC Overall Innovator of the Year Award in 2017.

2. Research Strategy

Our fundamental ethos is scientific excellence, with a strategy focusing on growing our disciplinary strength and breadth. Our strategy enables expanding scientific excellence across our research portfolio by providing the means to invest and build complementary capacity, by providing a research environment that attracts and retains the best scientists, and by embedding responsible research and innovation at the core of our research.

UoA5 research is facilitated, supported and coordinated by the higher-level Faculty of Life Sciences Strategy through the Faculty Research Committee, and overseen by a pan-Faculty Health and Life Sciences Research Strategy Committee co-chaired by Stephens (UoA5). As part of the institution-wide integrated planning process, annual reviews by the Schools, Faculty Dean and Faculty Research Director ensure a coordinated approach. This enables the best integration of all research activity across all Main Panel A UoAs, including maximising the impact of strategic appointments which can be targeted to give added value across both the Life Sciences and Health Faculties.

Over the current assessment period we have achieved success through the strategic aims from REF2014 (denoted by * where relevant) and new aims in our continuously-evolving research strategy, in which the guiding policies are:

To Invest in People

UoA5 strives to foster a supportive, collegiate and high calibre research community, with strong research links to other Schools across UoB. We achieve this through a policy of targeted recruitment and progression, supporting the career development of all staff, improving equality and diversity and embedding a strong, ethical research culture. Our strategy has delivered:

- * *Recruitment* – We have continued to invest in excellence in research leadership, creating three new external professorial appointments and eight new lectureships since REF2014.
- Reflecting ongoing *career development*, 11 existing staff have been promoted to personal chairs over the assessment period.
- * We have supported 19 ECRs in the award of *prestigious competitive fellowships*; 12 of 14 (86%) have progressed to permanent positions at UoB following the end of their fellowships. UoA5 has supported one recipient of the new Vice-Chancellor's Fellowships (VCFs, see REF5a), who has now progressed to the award of an external fellowship (WT).
- Substantial engagement with the institutional *Bristol Clear* scheme for support and development of postdoctoral researchers and a specific support programme for externally-funded independent research fellows.
- UoB was an early signatory of the Concordat to Support the Career Development of Researchers. UoA5 staff have been proactively supported through inclusion as Researcher Co-Investigators (Co-Is) and appropriately costed named researchers in grant applications, promotion of postdoctoral research associates (PDRAs) through the grades to reflect their capabilities and experience, mentoring of PDRAs developing fellowship applications and interview coaching, dedicated writing retreats, mentored teaching opportunities to RAs,

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tailored career support for PDRAs, opportunities to work in our flourishing start-up and spin-out community.

- * *Training* for the next generation by growth of PhD student numbers through expansion and development of doctoral training programmes (DTPs) and further development of the Bristol Doctoral College (BDC) as a comprehensive resource for academic and pastoral support.
- * *Athena Swan Progression* from Bronze to Silver for both Schools, now preparing for Gold.

To Invest in Infrastructure and Facilities

Over this period there has been substantial investment in biological sciences research infrastructure at UoB. This has been at the core of our strategy to provide world-leading physical and digital infrastructure for our research.

- * £64m has been invested to establish a *new Life Sciences building (LSB)*, opened by Sir David Attenborough in 2015. This houses new advanced facilities for plant growth (GroDome (£1m)), for genomics and bioinformatics/computing (£2m) and cryogenic electron microscopy (cryo-EM) facilities (£1.5m) as part of the Bristol Wolfson Imaging Centre which specialises in combining confocal and EM imaging (further £1m updating confocal facilities) and serial scanning EM (BlockFace, £1m).
- The *new Faculty of Life Sciences* was created in 2018 to consolidate and expand biosciences research at UoB. This brings together research and education in the related Schools of Biochemistry, Biological Sciences, Cellular & Molecular Medicine, Psychological Science, and Physiology, Pharmacology & Neuroscience (PPN) with a combined annual research grant income of ~£36m.
- Commensurate with our research strategy, £4m has additionally been invested in refurbishment of an Animal Services Unit, including a large animal facility and an aquatics facility to support biosciences research; there have been further investments in flow cytometry (£2m), microfluidics (£2.5m), proteomics (£1.5m), bioimaging (£1m), high throughput robotics (£1m), Biological nuclear magnetic resonance (NMR) (£1m) and the genomics facility (£1.5m). These facilities are complemented by the expansion of the Advanced Computing Research Centre housing world-leading computational clusters for large parallel computing (£9.9m during this REF period), used extensively for data processing in the biosciences.

To embed Responsible Research and Innovation (RRI) into our Research Environment

- This is a strategic theme across the Faculty of Life Sciences and central to this UoA. UoB has created an Academic Lead for Research Improvement role as part of its commitment to formally joining the UK Reproducibility Network (UKRN), in which it plays a leading role. The Academic Lead (Munafò, UoA4) coordinates the activities listed here, enhancing a positive culture of research integrity and improvement.
- An integrated training and development programme *for staff and students* at all stages of their research career. Both Schools have prioritised research integrity training for all staff and students (section 2a). Online training is obligatory for staff within their annual staff review. One of the leads (Grierson from this UoA) is also currently Head of School for Biological Sciences and hence well-placed to highlight this awareness and training. We have embedded this work on research integrity and research culture within our doctoral

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training programmes (see 2c) and have developed a modular series of short courses on topics ranging from data skills to leadership. These courses are intended for researchers at all career stages (see 2a, 2c).

- Policy framework development especially linking to national activity in this area, including working closely with the UKRN. Staff from UoA5 (Cuthill) have also been integral to the development of national policies for animal use in research (ARRIVE).
- Dedicated expert academic and research *professional support and mentoring* at all career stages, including support for UKRN Local Networks.
- Assessing the current issues that lead to academic staff feeling pressured into taking “short cuts” and consider wider cultural changes.
- Through our partnership with ten other UK institutions that are formal members of UKRN we are coordinating institutional policy statements on research transparency and the use of responsible metrics. This ensures greater interoperability across the sector and implementation of these statements.

To aid the Dissemination and Promotion of Research

The promotion of open research and research integrity is at the heart of our research culture, supported by our environment and organizational structures at different levels:

- *Multiple seminar series* run across the Schools with approximately 150 seminars given in a typical year, all of which are actively promoted primarily via weekly university wide emails and newsletters. In addition to the flagship School seminar programmes, there are more specialist series (e.g. Workshops in Ecology and Behaviour, the Round table talks, BrisSynBio series) and others of lesser formality which particularly engage earlier career researchers (e.g. ‘Chalk talks’, ‘Snapshots’ and ‘Focal Point’ series).
- UoA5 researchers are *enthusiastic promoters of their research*, frequently speaking at prestigious national and international conferences and public lectures, as well as being frequent contributors to diverse local, regional, and national outreach programmes.
- The *‘Benjamin Meaker’ scheme* hosts academics/distinguished professors from around the globe to spend from 4-52 weeks at UoB during which time seminars are delivered, along with collaborative research studies. During the period of assessment this has funded four visits to the UoA of prestigious staff from the US, Canada, Chile and Switzerland.
- *Research leave opportunities* are also available to UoB staff via our Bristol University Research Fellowship scheme providing relief from teaching and other duties, usually focused around undertaking a specific piece of research either at home or away; these have been used by seven UoA5 staff in this REF period.
- Staff initiate and frequently engage with *high profile outreach opportunities*. These include the international ‘Soap box science’ movement, initiated by Seirian Sumner who was at Bristol during the assessment period (‘Points of Light’ award from the Prime Minister), along with ‘Skirting Science’ and ‘Ada Lovelace Day’, all of which are aimed specifically at inspiring women scientists, and the pub-based ‘Pint of Science’ series for which Bristol is a hub. These have been key elements of both School’s Athena Swan silver awards.
- The Schools run *frequent outreach activities with school children and the general public* (e.g. Invincible participatory theatre production, SynBioExpo art exhibit), as do all the URIs. Staff are also regular contributors to radio and television programmes and podcasts that popularise their science (e.g. David Attenborough documentaries, In Our Time, Tweet of the Day, Farming Today).

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- The University was an *early adopter of open access for outputs* with 'gold' level access a requirement for essentially all publications, funded by core funds when necessary. Compliance (95%+) is managed and simplified at School level with office staff uploading data and papers. There is also a central repository for pre-prints and supplementary data, and a long-term research data storage facility (RDSF) operated centrally to ensure retention of key data. The press office frequently promotes high impact and high interest research outcomes.
- UoB has *robust policies regarding research governance* including infrastructure, data storage and management, use of animals and human tissue in research, grant management and regulatory issues. These are augmented by on-site training in research ethics. These areas are underpinned by the activity of Research and Enterprise Development (RED), a group of more than 80 staff with specialist skills and training who work with academics and researchers to help sustain and grow research activity and ensure governance (REF5a).
- All our doctoral training programmes include *specific training in research dissemination and presentation skills* and provide frequent opportunities for students to engage in outreach activities. These include presentations to local schools and groups on even bigger stages: e.g. our BBSRC South West Biosciences (SWBio) DTP students have become a regular and highly acclaimed presence (in 'Einstein's Garden') at the annual Green Man Festival in Wales (audience 25,000) with their hands-on presentations of topical bioscience issues. They are also regular contributors to the Cheltenham Science Festival (~30,000 attendees annually), New Scientist Live (40,000+ attendees), Bristol Festival of Nature (c.35,000 attendees annually), Big Bang UK Young Scientists and Engineers Fair, and Royal Society events.

To drive University-wide, long-term objectives

Biosciences research remains fully embedded in UoB's long-term research plans, as evidenced by:

- *Future Investment in Research Infrastructure*: We plan to continue to build on the substantial investments we have made during this period, for example those detailed in section 2 above. Some of these are being pursued at a regional level, notably through the Great Western 4 (GW4) network with the Universities of Bath, Exeter, and Cardiff (proven successful in establishing the cryo-EM facility). We anticipate regional facilities to become more common in the future; Bristol is well-placed and well-equipped both in terms of infrastructure and personnel as a South West centre of excellence.
- Building on the new LSB and Faculty, a major University activity is the *development of another campus* (Temple Quarter in the city centre, estimated investment £460m including £71m of matched funding from philanthropic and industry partners) within the next five years. This will enable expansion into new programmes focussed on digital innovation and enterprise, advanced computing and quantum technologies, all areas that will impact much of the future direction of biosciences research and its implementation. The Schools within UoA5 are already developing novel programmes for the new campus (e.g. degrees in Biology with Innovation & Entrepreneurship, Biophysics with Innovation), and these will shape future thinking and research activity.
- *Climate Action Plan*: Bristol was the European Green Capital 2015 and the first UK university to declare a Climate Emergency (following a petition started by students in the School of Biological Sciences). There is a Climate Action Plan formulating a rapid reduction

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in carbon footprint towards net zero. It includes LEAF accreditation for labs, only traveling internationally when fully justified and then offsetting any environmental costs, optimising waste management, and incorporating sustainability-related issues into our teaching and postgraduate training programmes.

Major achievements of research groupings underpinned by this research strategy:**Ecology, Environmental Change and Evolutionary Biology (10 FTE, research funding ~£7.3m)**

Work in this area concentrates on how genetic, ecological and ecosystem-level factors influence the way that biological systems, and their underpinning roles in all human economies, will respond in the face of environmental change. This is complemented by studies into the evolution of life and maintenance of diversity at different levels of biological organization, highly linked with investment in advanced computing and genomics. Researchers in this theme are active in two URIs: the Cabot and Jean Golding Institutes. For example, the impacts of climate change on the world's forests (Jucker), persistent climate change impacts on tsetse vectors of trypanosomiasis in sub-Saharan Africa (English), bat conservation policies (Jones; see impact case), and the international Urban Pollinator Project (Memmott; see impact case).

Research highlights include:

- A positive biodiversity-productivity relationship in global forests and that continued biodiversity loss will result in an accelerating decline in forest productivity worldwide (Jucker: *Science, Nature, PNAS, Ecology Letters*)
- A first national-scale assessment of floral resource provision has afforded new insights into the links between plant and pollinator declines, offering considerable opportunities for conservation (Memmott: *Nature, Nature Ecol & Evol*).
- Body size shifts and early warning signals preceded the historic collapse of whale stocks and signals of recovery in ecological systems (Clements: *Nature Ecol & Evol, Nature Comms, Sci Adv*).
- Discovery of the two-domain origin of life and that the first *Archaea* were anaerobes; quantifying the cumulative impact of horizontal transfer on archaeal genome evolution (Williams: *Nature Ecol & Evol, PNAS*).
- New genomic and fossil evidence of life's early evolution and eukaryotic origin (Pisani: *PNAS, Cur Biol*)
- Within genomic islands, genetic changes related to breeding preferences are the first to diverge during speciation. (Genner: *Science, Nature Climate, Nature Ecol & Evol*).
- Deduction of the minimal protein-coding genome of the first animal, uncovering an unprecedented increase in the extent of genomic novelty during the origin of metazoans (Paps-Montserrat: *Nature Comms*).

Future strategic plans will centre on a growth in the area enabling a greater diversity in our impact, including cultural impact through engagement with consultancies and the media. To expand this area, we have already appointed three new early career members (Jucker, Montgomery, Clements) with two further staff due to arrive in 2021 (Griffiths: Biodiversity and ecosystems function, UK Research and Innovation (UKRI) Future Leader Fellowship recipient; McGregor: molecular basis of host-parasite interactions in African trypanosomes, current BBSRC DPF holder). We will also focus on expanding the evolution theme in both the Cabot Institute

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(Global Change) and the Jean Golding Institute (Data) – the URIs enabling closer integration of the ecological and evolutionary research community of biological, earth and social scientists, policy workers and stakeholders.

Behavioural Ecology and Sensory Biology (12 FTE, research funding ~£11.0m)

This research theme centres on understanding the fundamental basis of animal behaviours and their sensory ecology. This lies at the heart of some of the greatest challenges the world faces and our aim is to discover creative solutions for the effects of human influence on the natural world. Focal areas are animal camouflage, communication, group conflict and the effects of light, electromagnetic and sound pollution on animals. Impact that has resulted from this area includes new companies (e.g. Azul Optics Ltd and winner of the BBSRC Innovator of the Year Award 2017), informing new policy (Cuthill, Jones, King, Radford) and social impacts (Impact Strategy, see section 1c). Since REF2014, there has been an increasing emphasis on integrative approaches to our studies, with significant new appointments (Stroeymeyt, Ioannou, King, Grueter), substantial investment including industrial funding, and considerable media attention to the impact of anthropogenic noise.

Research highlights include:

- A new derivation of Hamilton's rule accounting for stochastic changes in natural environments. This revealed missing fitness effects in the evolution of animal societies (Radford: *Nature*, *Curr Biol*).
- How noise pollution impacts animal behaviour in multiple ways including anti predator responses, foraging, fitness and habitat selection. (Radford: *Nat Comms*, *Curr Biol*)
- Identifying changes in behaviour when animal groups are infected with a pathogen and how behaviour is altered for the protection of the colony (Stroeymeyt: *Science*).
- Animals combine aposematism and camouflage without necessarily compromising the efficacy of either strategy. Bright colours may act as a highly salient close-range aposematic signal, while simultaneously minimizing detectability to distant observers (Cuthill: *Curr Biol*, *PNAS*).
- Discoveries of new forms of colour vision and sensitivity to the polarization of light (How, Roberts: *Science*, *Curr Biol*, *Nature Comms*, *Sci Adv*, Impact Case).
- The discovery of moth wings acting as acoustic meta-materials and new types of ultrasound production (Holderied: *PNAS*).
- The mechanisms of how insects can detect weak electric fields (Robert: *PNAS*).

Future strategic plans: Priorities include furthering understanding of behaviour in the context of global change, behavioural genomics, and growing research in bio-informed sensory engineering systems. We will focus on building new partnerships between our strengths in discovery-led behavioural and sensory biology research with leading areas in robotics (Bristol Robotics Laboratory), engineering, URIs (particularly Bristol Digital Futures), and Bristol Vision Institute.

Plant and Agricultural Sciences (10.3 FTE, research funding ~£11.8m)

Research in this area focuses largely on plant and agricultural biology, tackling fundamental questions of how to sustainably produce more food crops and animal feed in an increasingly unpredictable environment. Since REF2014, substantial strategic investment has been made with new infrastructure (e.g. GroDome controlled environment greenhouse, high performance computing (HPC) for genome analyses), equipment funding (BBSRC-funded liquid handling system £320k) for the expansion of the genomics facility, and new appointments (Sparkes,

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Harrison). Research has been boosted via the formation of the Bristol Centre for Agricultural Innovation (BCAI), a £15m endowment-funded centre with a strategic initiative of financial support for early career fellowship holders. New networks have been created, including CONNECTED (COmmunity Network for africaN vECTOR borne plant viruses; Foster £1.5m, Impact case) and the Indo-UK Centre for the improvement of Nitrogen use Efficiency in Wheat (INEW) (Edwards).

Research highlights include:

- Characterization of polyploid wheat genomic diversity using a new high-density 90,000 single nucleotide polymorphism array (Barker, Edwards: *Plant Biotech J*; see impact case).
- PIN-mediated auxin transport is an ancient, conserved regulator of shoot development (Harrison: *Current Biology*).
- PhyB is required during the light-mediated systemic control of stomatal development and mechanistic insight into the effects of UV-A and CO₂ on plants (Hetherington: *Current Biology* x 4, *Nature Plants*).
- UVR8 activation stimulates multiple pathways that converge to block biosynthesis of the plant growth hormone auxin (Franklin: *Current Biology*, *PNAS*, *Nature Comms*).
- Iridoplasts are highly modified chloroplast structures adapted to increase photosynthetic efficiency in extremely low-light conditions (Whitney: *Nature Plants*).
- Light and a plant's circadian rhythm are integrated to regulate chloroplast transcription by a nuclear-encoded sigma factor (Dodds: *Current Biology*, *New Phytologist*).

Future strategic plans: We aim to build strength in discovery plant science research, including growth in research use of the agricultural platform at our Fenswood Farm agricultural facility, new strategic appointments, and increased use and expansion of in-house genomics and proteomics facilities in understanding plant and crop responses to global challenges. The BCAI endowment will enable these actions, providing additional improved support for ECR fellowship applicants.

Synthetic Biology: (9.8 FTE, research funding ~£12.5m)

Development of a new synthetic biology thematic area was a declared objective in our REF2014 submission. This has now matured with formation of the BBSRC/EPSRC-sponsored BrisSynBio Centre along with the Max Planck Institute (MPI)-Bristol Centre for Minimal Biology. The UoB flavour of synthetic biology has largely concentrated on a bottom-up philosophy with strengths in *de novo* protein design and application of artificial protein systems to a range of technologies, importantly including vaccines for COVID-19 and other infectious diseases. There is close integration with Biological & Organic Chemistry, such as the joint appointment of Woolfson (submitted in UoA8, a dual Chemistry-Biochemistry appointment) and collaborations with Mann (UoA8), and significant industrial links supported by technology development (e.g. membrane protein production (Berger, Collinson) and structural biology (Berger, Brady, Race, Schaffitzel). Many staff in this thematic area are also involved in the Molecular Biosciences and Dynamic Cell Biology thematic areas. Activity in this theme is directly aligned with the University Research Strategy and Bristol BioDesign SRI.

Research highlights include:

- Five companies spinning out into small and medium-sized enterprises (SMEs) since the last REF2014 (Impact case).

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- Synthesis of catalytically proficient and hyperthermostable *de novo* enzymes capable of stimulating oxygenation of stem cells during engineering of large cartilage tissue (Anderson: *Nature Comms* x 2).
- Novel and widely-used (worldwide >600 groups) methods for expressing protein complexes in insect cells (Berger: *Nature, Nature Methods, Nature Comms*). Development of Addomer technology, a novel and temperature-stable vaccine platform now being applied to COVID-19 (*Science Adv*, Imophoron spin-out, impact case)
- *Ab initio* design, production and structural characterisation of a series of oligomeric coiled-coil based channel proteins that are being developed for multiple uses (Brady, Sessions together with Woolfson (UoA8): *Science, Nature Chem, Nature Chemical Biology, JACS*).
- Novel computational methods for the *ab initio* design of α -helical repeat proteins (Parmeggiani (ECR): *Nature* x 2, *Nature SMB*).
- Mechanoresponsive solid-state photo-bioelectrochemical devices from pigment-protein multilayers (Jones: *Adv Materials*)
- Establishment of both the BrisSynBio Centre for Synthetic Biology (2015, BBSRC, £14.3m) and MPI-Bristol Centre for Minimal Biology (Director: Berger, 2019, £2.9m).

Future strategic plans: Supported by the MPI-Bristol Centre for Minimal Biology, the future strategy is to move *in vitro* successes into cells and other natural environments. Much of the synthetic biology work is highly translational, our priority is to expand more studies to direct applications in biotechnology and medicine. Our artificial protein systems are already finding diverse applications (see impacts and outputs in this submission) and our strategy is to build on these achievements. We envisage increased use of cryo-EM to support our design strategies, utilising the new in-house bioimaging facility along with the Titan Krios systems at Diamond. Advanced computing (HPC and Cloud) - Infotech Meets Biotech – is envisaged to be a key part of our design strategy and a major activity linking SynBio, Population Health and Advanced Computing, using quantum technologies to transform processing speeds of underlying work in this area (e.g. Oracle's Cloud infrastructure was used in Schaffitzel's COVID-19 *Science* paper) hence linking with plans for the Temple Quarter campus.

Dynamic Cell Biology (14.8 FTE, research funding ~£27.4m)

The cell is the fundamental unit of life. Our work across this broad and diverse area particularly aims to understand molecular mechanisms of membrane trafficking and regulation of dynamic complexes, within and between cells and at membranes, including the roles of the extracellular matrix and cytoskeleton. Cell biology research incorporates many other activities within UoB including epidemiology and clinical research, as demonstrated by closely integrated PhD training Programmes and cross-theme activities with the Bristol Heart Institute SRI and new Regenerative Medicine initiatives. Work in this cluster integrates with, and continues to drive the development of, our core facilities in Proteomics and Bioimaging. The academic managers of both facilities are submitted within UoA5. Cell biology research plays a prominent role in developing and applying advanced cell imaging techniques to study cellular function in relation to disease.

Research highlights include:

- Discovery of neuropilin as a receptor for SARS-CoV-2 infection (Cullen, *Science*).
- The roles of sorting nexins in the retromer complex as critical determinants of endosomal function in development, metabolism, and disease (Cullen: *Nature Cell Biology, Nature Medicine, Current Biology, PNAS, JCB*).

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- Development of animal models of wound healing including mouse, zebrafish, and *Drosophila* (Martin: *Cell*, *Dev Cell*, *Current Biology*, *EMBO J*).
- Molecular mechanisms of synaptic plasticity and neurotransmitter receptor dynamics (Henley: *Nature Neuroscience*, *Nature Comms*, *Cell Reports*).
- An immortalized adult human erythroid cell line for the scalable production of functional red blood cells, a discovery being translated with far-reaching impact for human health (Frayne & Toye: *Nature Comms*, *Scientific Rep*).
- Delineating the role of actin in preventing chromosome segregation errors (Mogessie (ECR): *Science*, *Cell*).
- Discovery of a novel route for priming macrophages with molecular memory during the immune response, pertinent to the process of wound healing (Weavers (ECR), Martin: *Cell*).
- A highly cited study demonstrating the critical role of mitochondria in cellular senescence (Carroll (ECR), *EMBO J*).

Future strategic plans: Our key aim is to continue to develop our multiscale approaches using molecular, cellular, tissue, and organism level approaches. These include the use of induced pluripotent stem cells (iPS) cells, organoids, multiple animal models, and development of cryo-tomography capability. Integration with Population Health Sciences through creation of a new EBI research strand developing projects through integration of genetic and other data from large cohorts, underpins this strategy. The Wolfson Bioimaging Facility, Flow Cytometry, Animal Services, and Proteomics Facilities are crucial to, and act as a catalyst for, many of these research programmes; we will continue to enhance capability in the combination of technologies for molecular, cellular, and whole organism imaging. Industrial partnerships with Leica Microsystems and Field Electron and Ion (FEI) have driven development in this area. We will also expand use of automation and big data approaches to understanding fundamental cell and molecular biology.

Molecular Biosciences (13.6 FTE, research funding ~£11.4m)

Biochemistry at UoB has a long and highly successful history of research in molecular recognition and enzymology, with a strong focus on quantitative understanding of the dynamics of catalytic mechanisms and substrate recognition. Strengths include: understanding protein-nucleic acid interactions that underpin fundamental processes such as DNA replication, recombination, repair, transcription, and bacterial defence mechanisms of restriction-modification and CRISPR-Cas; measuring motor function on protein and DNA tracks; understanding the enzymology of antibiotic synthesis.

Research in this cluster focuses on studies of macromolecular complexes, both their individual proteins and their assemblies. With the establishment of single-molecule techniques such as single molecule FRET, magnetic tweezers and other approaches to biomolecular measurement, this traditional strength has now evolved to encompass a broader range of techniques. This cluster seeks to extend provision of advanced biophysical techniques through links with Physics, Nanoscience and Chemistry, including computational approaches to enzymology (Mulholland, UoA8). New appointments within the period of assessment include Chambers, Cheung, Dodding, Schaffitzel and Van der Kamp. Many staff in this thematic area also have cross-over with the Synthetic Biology theme (Section D), and there is also close integration with the Dynamic Cell Biology theme (Section E), providing structural snapshots of cellular processes. Activity in this theme aligns with and is underpinned by the University Research Strategy and particularly with Bristol BioDesign.

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Research highlights include:

- Discovery of a druggable pocket in the SARS-CoV-2 Spike protein (Schaffitzel and Berger, *Science*).
- Determination of the structure of the target of Rapamycin (mTOR) transcriptional complex 2 using cryo-EM (Schaffitzel: *Mol Cell*, *Nature Comms*).
- Delineation of the mechanism of membrane protein insertion and proton-motive-force-dependent secretion through the bacterial holo-translocon (Collinson and Schaffitzel: *PNAS*, *eLife*).
- Discovery of key molecular mechanisms in transcription repression, repair and genome stability (Chambers (ECR): *Mol Cell*, *Cell Reports*).
- Elucidation of the structural basis for translocation by AddAB helicase-nuclease and its arrest at χ sites (Dillingham: *Nature*).
- Identification of novel activators of the kinesin-1 motor complex driving remodelling of the microtubule network (Dodding (ECR): *PNAS*, *Neuron*).
- Reconstruction of the bacterial transcription-coupled repair complex to allow its study at single-molecule resolution (Savery: *Nature*).
- Single-molecule studies to directly measure R-loop formation by CRISPR-Cas9 and Cascade complexes (Szczelkun: *PNAS*).
- Verkade, a world leader in combining light and electron microscopy (CLEM) techniques, has continued to develop this expertise leading to discoveries such as how the ESCRT-III complex controls nuclear envelope reformation (*Nature*), the role of p75(NTR)-dependent activation of NF- κ B in transcription in diabetes after limb ischaemia (*Nature Comms*), and in engineering synthetic cytoplasmic scaffolds in bacteria (*Nature Chemical Biology*).

Future strategic plans: Increased application of high-resolution structural biology and cellular electron tomography using the new in-house GW4 Cryo-EM facility along with the Titan Krios systems at Diamond and Cloud and HPC computing, together with fluorescence and correlative microscopies for the study of macromolecular assemblies. We will build on existing strengths in molecular enzymology and mechanochemistry to ensure we remain internationally competitive in this area. Further development of research links with, particularly, the physical sciences (physics, chemistry, mathematics, engineering) are central to our future research within this thematic area, including ever closer alignment with the related synthetic biology studies. One important link is the development and application of computational (molecular) techniques to predict molecular processes. The new appointment of Van der Kamp (ECR, awarded tenure post-fellowship) supports this strategy.

3. Impact strategy

Our impact strategy is designed to allow us to work in the best ways to create beneficial change in society, the economy, culture and in delivering solutions to some of most profound challenges facing our natural world in the 21st Century.

Our strategy is common for both the Schools of Biological Sciences and Biochemistry, and across the Faculty as a whole. Each School has a dedicated staff member nominated as its Impact Lead. These are academic staff with direct experience and success in delivering impact from their research. Their role is to proactively identify potential impact, and then work with the Knowledge Exchange Associates (KEAs, part of the institutional RED team, see REF5a) to advise and encourage staff and ensure best practice. The University has appointed a dedicated Advisor on

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Business Development who liaises directly with academics in the UoA and industry to develop partnerships at scale.

The guiding policies in our impact strategy have achieved the following successes:

Realising impacts through follow-on funding

Over the current assessment period the University has been awarded ~£7m in Impact Acceleration Accounts (IAAs) from BBSRC and EPSRC.

- We administer two BBSRC Flexible Talent Mobility Awards (£386k) which have provided a devolved portfolio of support for short term placements with industry. These awards have supported staff to undertake industry engagement events (e.g. Race, Zentraxa).
- KEAs have developed a toolbox for industry engagement which has been used by our staff to e.g. develop new international research collaboration networks (e.g. Foster, CONNECTED).
- UoA5 staff have also received funds from the University's devolved Global Challenges Research Fund (GCRF)-IAA budget which supports international impact delivery activities. Staff time for translational work is protected via allowances in workload models or impact 'sabbaticals' (either funded via the IAA or externally e.g. RS Industry Fellowships to Race (with Zentraxa) and Dodd (with LettUs Grow)).

Research translation

This area has advanced significantly since REF2014 with the creation of a central Translational Research Hub (TRH) within RED. This consolidates staffing and funding resources for the translation of our health and life sciences research.

- Oversight of the TRH is provided by a Steering Group chaired by the PVC Health (Iredale, UoA1) and includes the Faculty Deans of Life Sciences (Tavaré) and Health (Norman, UoA1) and our Advisor on Business Development, Dr Richard Seabrook (formerly Head of Business Development at Wellcome).
- The TRH provides a single-entry point for all researchers to translate their life and health science-related research. It currently comprises a team of eight FTE support staff, an increase of six FTE during the current REF period, which substantially streamlines engagement.
- The TRH also provides simplified access into the university for companies seeking to explore engagement, commercialisation and collaborative opportunities with academics in the health and life sciences. The TRH has overseen £3.9m of devolved portfolio funding received during the assessment period (Medical Research Council (MRC) Confidence-in-Concept and Proximity-to-Discovery awards, WT Translational Partnership Award (TPA) and BBSRC IAA and Flexible Talent Mobility Award (FTMA)).

Developing clear pathways through business incubator and venture fund links

SETsquared (support for new technology companies), Unit DX and expanding soon to Unit DY (laboratory space for emerging biotechnology start-ups).

- UoA5 staff have greatly benefited from the University's Unit DX 'deep-tech' incubator hub which provides laboratory space, advisors and links with financiers. Examples of recent spin-outs generated from research in this UoA in the assessment period include Azul Optics (tools for macular degeneration detection, Roberts), Zentraxa (biopolymers as

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adhesives, Race), Rosa Biotech (biosensing, Boyce & Woolfson) and Imophoron (novel vaccines including COVID-19, Berger).

- Bristol life science spin-outs are benefitting from the launch of Science Creates Ventures, a £15m EIS venture capital fund through partnership with the University.
- In addition to the impacts described in REF3 there are multiple emerging impacts in early-stage development. One example with substantial potential future impact and reach is Frayne & Toye who, together with NHS Blood & Transfusion, are using stem cell technology to produce artificial blood substitutes.
- The University has a well-established policy for the re-distribution of profits from patents and spun-out companies to its contributing employees.

Impact training

Both schools within this UoA have embedded a culture of impact awareness as an integral part of our education and research-training activities in all postgraduate level programmes. This includes:

- An innovative 'Science and Society' taught unit is taken by all Masters-level final year Biochemistry students and as part of the initial taught year of the SWBio DTP programme. This unit includes sessions from enterprise champions, guidance on routes to commercialization and preparation and a presentation pitch by the students for a virtual biotech product in a 'Dragon's Den'-style competition.
- Training is provided for all staff and students by the Centre for Innovation and Entrepreneurship, established by the University in 2016. All our students, and staff, are also encouraged to enrol on non-credit bearing online units such as Innovation and Enterprise, Global Citizenship and Sustainable Futures which form part of the Bristol Futures programme.

Societal Impact

Across UoA5, researchers are at the forefront of public engagement, providing societal impacts at a variety of levels, e.g.:

- The hugely popular University Botanic Gardens (Director Memmott from UoA5) is a centrepiece in UoA5's extensive engagement with the city of Bristol. There have been successes in events such as the Impossible Garden (Luke Jerram, (18,000 visitors)), the annual Bristol Bee and Pollination Festival (typically 5,000 visitors), public lectures by Monty Don (2015, 500 tickets sold out in under 4 hours).
- There has been extensive collaborative work with the local BBC Natural History Unit, for example on their flagship Blue Planet series (highest annual viewer ratings in the UK (~14m) and sold to over 50 countries worldwide), and with many other natural history films companies, cementing Bristol at the centre of World Natural History film-making industry.
- Three of our submitted Impact Cases (Cassava network, Urban pollinators, Bat conservation) relate directly to societal and policy impact(see REF3).

2. People**1. Staffing strategy and staff development**

Our staffing strategy remains to appoint, support and develop the very best individuals whose research interests complement and enhance our research themes, both existing and in new strategic directions. We fervently believe that it is individuals who drive the very best research

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forward through their enthusiasm, intellectual rigour, dedication and intense curiosity. Following this ethos, during the review period we have made notable appointments to core-funded posts as well as through prestigious personal fellowship awards.

New external appointments since RAE2014:

- *Three at senior (Professorial) level:* Berger strengthens our structural biology research in addition to forming the nexus of extensive collaborations on his Multi-Bac expression system, Beaumont emboldens our mathematical expertise as applied to biological systems and Schaffitzel has established cryo-EM at UoB including a joint facility for the GW4 institutions.
- *Other strategic appointments* include Cheung (Molecular Biosciences), Clements (Ecology and Evolution), Dodding (Molecular Biosciences), Gorochowski (Synthetic Biology), Grueter (Behaviour & Sensory), Harrison (Plant and Agricultural Sciences), Ioannou (Behaviour and Sensory), Jucker (Ecology and Evolution), King (Behaviour and Sensory), Montgomery (Ecology and Evolution), Stroeymeyt (Behaviour and Sensory), van der Kamp (Molecular Biosciences), Williams (Ecology and Evolution).
- *We continue to attract exceptional ECRs* through prestigious 5-year fellowship awards (3 x ERC starter, 6 RS URF, 1 x UKRI FLF, 1 x BBSRC DPF, 3 x NERC IRF, 1 x Dorothy Hodgkin, 1 x Branco Weiss, 3 x WT SHDFs and 1 x CRUK). We proactively retain these key staff by appointing them to permanent positions. Since 2014, 86% (12 out of 14) of our fellows ending their fellowships have transitioned to permanent academic staff.
- The University has also recently instigated its own competitive *Vice-Chancellor's fellowship scheme* through which we appointed Carroll who subsequently secured a 5-year external fellowship (WT). This is part of our strategy to support the development of ECRs ensuring the sustainability of our science.
- Staffing strategy has led to a *balanced age profile* including a substantial number of ECRs, many with tenure-track type appointments, representing a major investment in the future of the discipline (Table 1):

Age range	25-35	36-45	46-55	56-65	>65
Proportion of academic staff	6%	32%	32%	27%	3%
% Female	20%	36%	20%	24%	33%

Table 1: Academic staff age profile

Internal promotions via an EDI-directed procedure form a key means of recognising staff achievement in research, teaching and collegiality.

- Eleven members of this UoA (half previously on research fellowships) have been promoted to personal chairs in the review period (Dillingham, Franklin, Frayne, Genner, Hanley, Race, Radford, Roberts, Toye, Verkade, Yallop).
- Engagement with translational research is a significant criterion for promotion of our academic staff. UoB is also strongly supportive of non-commercial impacts from our research which often have national and global reach. These include developing influential policies (e.g. on animals in research (Cuthill) or urban pollinators (Mommott)) or establishing and promoting networks to improve global food, health and sustainability (e.g. CONNECTED (Foster) and improved yield wheat strains (Edwards & Baker)).
- Excellence is also recognised through externally-funded personal awards which form a key component of our large-scale funding. Over the assessment period Berger, Collinson, Cullen, Dillingham, Martin & Schaffitzel have held Wellcome Trust Senior Investigator

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Awards (all >£1m), ERC Starter (Whitney, Montgomery, Stroeymeyt & Curnow, each >€1m), Consolidator (Radford, ~€2m) and Advanced (Berger, Robert & Szczelkun, each >€2m) awards, and a Royal Society Professorship (Cullen).

Staff Development

All staff are supported in their careers through mentoring and staff development projects (including leadership, teaching, or management courses) and through annual staff review and development appraisals (taken up by >90% of staff).

- *A common Faculty-level workload model* provides transparency in balancing teaching, research, administration, translational and wider academic contributions. Newly-appointed staff have reduced teaching and administration loads to facilitate establishing successful research programmes.
- *Senior staff mentor new staff*, especially research fellows. In Biology, we trialled external Mentors for all academic staff in 2015 (PDRAs included). Mentors are ex-UoB staff who host in-house sessions with academic staff and PGs, providing career and well-being support (reporting to EDI Committee). This led to clear improvements: in 2014, only 60% of men and 38% of women felt they received effective career support. In 2017 this had risen to 70% of men and 63% of women (Staff Satisfaction Survey). This scheme is now used across the UoA and Faculty.
- *All new lecturers join the CREATE scheme*, allowing participants to become Fellows of Advance HE (see REF5a). For female members of staff, there are specific leadership schemes, namely the Female Leadership initiative and AURORA.

Tailored support for Early Career Postdoctoral Researchers

A major part of our workforce (~65%) are PDRAs and are central to our research success. The University operates an inclusive policy to improve job security for those employed on fixed-term contracts, ensuring they are named researchers or Researcher Co-Is on grant applications where possible and have priority for upcoming vacancies.

- *PDRAs have access to extensive training opportunities* and are treated identically to core staff for annual staff review and training purposes. Much of this is supported via 'Bristol Clear' (see REF5a), an institution-wide body created in 2018 to provide mentoring, guidance on research careers and links to services and opportunities across the University and externally.
- The *UK Concordat to Support the Career Development of Researchers* has been adopted by the University and our employment practices and policies operate in line with its principles. During the assessment period there has been an increase (+6) in the number of senior PDRA with Researcher Co-I status on awarded grants. The University has held an EC HR Excellence in Research Award since 2010 (renewed in 2019).
- All research staff attend *careers talks* focused on topics including research funding, becoming a new research leader, industrial, communication and policy opportunities. The Biosciences PDRA community additionally arrange their own events to support careers, provide guidance and a platform for ensuring their voice is heard.
- Career development is further supported *through ongoing availability of successive postdoctoral fellowships* including bridging funds where required from EBI, BICAI and School funds. CV checks have been added as part of staff annual review process to encourage staff to discuss career advancement and development opportunities with their line managers.

2. Equality, diversity & inclusion

As reflected by our progress in both Schools through Bronze (2014/15) and then Silver Athena Swan awards (2018/19), the unit has made significant progress over this REF period in improving EDI:

- In compiling this current submission, we have considered all our independent researchers via our institutional procedure (see REF5a) and provided opportunities for earliest stage researchers to additionally request their consideration. All qualifying staff could (confidentially) apply for reduced numbers of outputs based on career stage, maternal/parental leave, disability or health circumstances. These requests have been considered centrally and confidentially, including a right of appeal. We are therefore confident that the submission faithfully reflects the complete researcher composition of our two academic Schools.
- *Support for staff with disabilities* is on a case-by-case basis to ensure individual requirements are met regarding e.g. building and laboratory accessibility and other needs. Impact of disabilities forms a specific tenet in annual staff reviews, in assigning workloads, access to training and conferences, and in assessing cases for promotion. Schools have discretionary funds to enable staff with disabilities to fully engage with research, e.g. a short-term RA has been provided in one instance. Recruitment of people with disabilities is a current focus of EDI teams, to ensure our job adverts are reaching the widest range of people, including those who may require the adverts to be in a different format. Of our staff, 6% currently identify as having a disability.
- All staff are protected by an *Appropriate Behaviours Policy* which provides pro-active routes for dealing with harassment, bullying and other inappropriate behaviours, and includes access to both a 'Report + Support' tool and an in-house mediation service where appropriate. Within our schools we have designated staff champions for EDI generally and for specific minority groups (e.g. Black, Asian and Minority Ethnic (BAME)) accessible to both staff and students. Each school website has well-developed pages devoted to equality, including links to sources of support. The University is a member of the Stonewall Diversity Champions programme and both Schools host regular events to raise awareness of LGBTQ+ issues.
- In each School there is now a *focus on intersectionality* with targets to improve gender balance and diversity in recruitment including flexible working as standard in all job adverts (which are put through a language decoder to highlight language bias) and compulsory mixed gender shortlists with positions being re-advertised if necessary, to achieve this. We have also recently used a recruitment agency who specialise in the recruitment of BAME scientists (currently 5% of tenured staff identify as BAME). We are pro-actively raising the profiles of STEM researchers in underrepresented groups via The Inclusive Research Collective and The Learning Forum. Deliberately gender-balanced seminar programmes operate in both Schools. Within UoA5, 27% of tenured staff are women, compared with ~53% of PhD students and ~52% of postdocs. Gender balance is improving but, especially at higher levels, we are fully aware there is still much work to be done. Both Schools are currently preparing to upgrade their existing Athena Swan Silver awards by bidding for Gold status at next renewal (2021/22).
- The unit highly *values family-friendly work arrangements* and these are reflected in, for example, scheduling seminars only within core hours (recorded for those unable to attend), flexible working arrangements, and reduced workload arrangements (e.g. minimal teaching for 6-12 months) for those returning from generous maternity, paternity or shared parenting entitlements. This is also available to those returning from long-term illness or with caring

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responsibilities. Staff who wish to attend conferences but have dependants can apply for financial assistance via a Travel Fund. There are also school-specific parental leave booklets describing what individual schools do to support staff during pregnancy and parental leave, above that given by the University. Flexible working is the 'norm': a recent staff survey revealed that 45% of male respondents and 62% of female respondents work flexibly. This is usually an informal agreement with line managers reflecting positive working relationships. Options are available for career breaks for up to a year or more for parents and carers (e.g. career breaks of up to 24 months have been arranged for staff whose partners have had to attend extended training in the US) and there is a highly-regarded on-site workplace nursery.

- *Staff (and student) mental health* has emerged as an area of priority concern at UoB and has led to the establishment of bespoke mental health policies for both staff and students. These are supported by substantial in-house counselling and health services (additional £1.5m from 2018), an employee assistance programme telephone advisory service, Mental Health Champions within both of our Schools, and a student support well-being service of approximately 30 full-time staff covering both undergraduate and all research students. A specialist group for young person well-being has been established, supported by a University-funded VCF to research this area. Multiple smaller scale interventions also take place: for example, there was a focus on the prevention of suicide in men in November 2019, there are bi-annual staff well-being fairs, World Mental Health Day is marked annually with a series of well-being activities, and 'Pets as Therapy' sessions have been introduced. Mental health remains an ongoing priority within the University.

Future Strategic Actions

Continuing to work towards a more diverse range of speakers for seminar series; ensure that provision for speakers with caring responsibilities is promoted at invitation; better diversity with respect to gender and race within senior staff; both Schools are applying for Athena Gold level award.

3. Postgraduate Research students

The unit hosts a vibrant community of doctoral and masters-level research students, and typically graduates 30-40 doctoral students each year attributed to UoA5 (see REF4a).

Cohort Structure and Training programmes

Annually our postgraduate student body typically contains about 170 PhD and 60 MRes students, born in 21 non-UK countries (6 EU, 15 non-EU) and 53% female. There is a strong focus on diversifying the cohort of research students, with specific policies being actioned by the BBSRC SWBio DTP and WT.

- PGR student administration is managed through a single *Faculty-level Graduate School*, which in turn is integrated within BDC, a University-wide activity that provides a clear and visible focus (external and internal) for postgraduate research and training at UoB. BDC provides extensive training resources and runs many PGR-focused activities, both academic and social, including an annual and very popular 'Three Minute Thesis' Competition. Additionally, BDC has established well-being programmes and offers regional (GW4) activities which build communities and support networks at this early career stage.
- The majority of PGR students within the unit belong to *Doctoral Training Programmes* which provide structured research training, particularly in Year 1, most operating on a 1+3 year model. For example, the BBSRC-funded SWBio DTP (SW cross-institutional

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partnership lead by UoB (~£30m, Director, Brady; Deputy, Lane), includes Bath, Cardiff, Exeter, Rothamsted, the University of the West of England (UWE) Bristol, Swansea, Plymouth; ~130 PGRs across the partnership with typically ~50 based in UoB) operates a taught first year in which students complete three taught units (Bioinformatics & Statistics, Science & Society, Coding Skills) and undertake research projects in lab rotations, providing an MRes exit route at the end of Year 1 if required. The vast majority (>95%) of students continue to years 2-4 for their doctoral research project. Throughout they benefit from a wide range of cohort activities such as an annual student conference, scientific industrial site visits, thematic-based seminars, a three-month internship and student-arranged away days. They also have access to the jointly managed Enterprise Zone located at UWE Bristol where they can gain support for developing commercialisation ideas including up to 12 months fully funded sponsorship on graduation. The strong cohort identity developed in these programmes provides valuable and much appreciated support for students throughout their doctoral training.

- The UoA also hosts students from many other doctoral training programmes. These include our WT 4-Year PhD Programme in Dynamic Cell Biology (renewed 2019; Director, Cullen), which has operated alongside a second WT 4-year PhD programme in Neural Dynamics throughout much of the assessment period, the GW4 MRC Biomed DTP, the NERC GW4+ DTP and Fresh Centre for Doctoral Training (CDT), and several EPSRC CDTs: Nano and Functional Materials (BCFN), in Chemical Synthesis (Bristol Centre for Complexity Sciences) and Synthetic Biology (SynBioCDT).
- Additional students are funded by charities and, internationally, the ERC, foreign governments (e.g. Malaysian Government, China Scholarship Scheme) and overseas research agencies. We also host 10-40 Masters by Research students per annum, many of whom stay on for doctoral study.
- *University of Bristol postgraduate scholarships* enable us to attract the very best UK and overseas students in addition to Dean's Scholarships and the China Scholarship schemes.

Supervisory Structure

Policies and structures are matched in both Schools, and across the Faculty to ensure best practices for our students.

- All PhD students have at least two supervisors, with some second supervisors from outside their School, which encourages good practice, collaboration, and interdisciplinarity.
- In addition, they have a separate advisory panel with whom they meet regularly and who make progression decisions.
- Student well-being is of paramount importance to us. To match the diversity of issues that can arise students have access to multiple forms of support: supervisors/advisory panel, School Graduate Tutor, Faculty-based Well-being advisers (team of five), and the Student Support Service including access to counselling, GPs/medical and disability advisers. Informal support is also provided by most of the DTPs which endear a strong cohort-based sense of community. Arrangements for part-time study, medical suspensions and extensions are enshrined in the University student and study regulations.
- Exchanges between sectors are strongly encouraged and supported for all our PhD students (and ECRs). For example, SWBio DTP students must complete a three-month professional placement outside of academia as part of their training; this scheme has seen a diverse range of placements within e.g. start-ups in local incubators Unit DX and SETsquared, large pharma, charitable and government sectors, both within the UK and

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abroad. The success of this scheme has led to all our PhD students being offered similar placements should they choose them, with support available from the University Careers Service internship scheme.

- Students nearing the end of their training are also eligible for FTMA financial support to encourage placements. UoB is the recipient of £386k BBSRC FTMA funding which is available for early career researchers to develop a collaborative project, scale up an existing relationship or develop new projects with industry partners through a placement.

Future Strategic Actions

Consolidate and extend programmes to increase PGR student numbers; ensure the advantages of these programmes are also available to all our postgraduate students; extend the range of training available matching their own, sponsors' and employers' demands.

3. Income, infrastructure and facilities

1. Income

UoA5's external research grant income resulted in a spend of approximately £81m over the assessment period (see REF4b).

- Our *income is derived from diverse sources*, primarily competitive, including UKRI, National Institute for Health Research (NIHR), major charities and industrial partners. In addition to the extensive support gained through early career awards (detailed below), major sponsors are the BBSRC, WT, Horizon 2020, MRC, and NERC and ERC. The breakdown of these grants is 57% UK Research Councils, 27% UK charities, 6% UK Government and Industry, 9% EU and 2% Overseas. Total annual grant income has been consistently maintained and increased over the assessment period, despite escalating challenges in the financial environment.
- There have been *distinct successes with international awards*, notably the European Research Council: ERC Starter (Whitney, Montgomery, Stroeymeyt & Curnow, each >€1m), Consolidator (Radford, €2m), and Advanced (Berger, Robert & Szczelkun, each >€2m) grants. Other major grants awarded since 2014 include Toye (NIHR, £3m), Berger (WT, £2.6m), Cullen (MRC, £1.8m), Edwards (BBSRC, £0.8m + £0.6m), Foster (BBSRC, £1.7m), Holderied (EPSRC, £1.6m), Henley (MRC, £1.2m), Bailey (MRC, £2.5m), Race (EPSRC, £2.2m), Stephens (BBSRC, £0.8m and a £1.7m component of a BBSRC sLoLa with Martin and Hammond), and Chambers (CRUK, £1.1m) as well as WT Investigator Awards (all £1m – 1.5m) to Berger, Collinson, Cullen, and Schaffitzel and WT SHDFs to Mogessie, Carroll, and Weavers (all ~ £1m).
- Our *19 five-year fellowship holders since REF2014* have been provided with between £20k-£100+k start-up funds depending on requirements; in addition, support is provided for strategic platform technologies (especially genomics and bio-imaging) providing subsidised access for early career and new appointments.
- Strategically important income is also provided by *University endowments*. For example, the Lady Emily Smyth endowment, managed through the BCAI (~£13m in investments), supports researchers across this UoA. Through its earnings (~£0.3m p.a.) it has supported research of agricultural relevance via pump-priming awards, fellowship start-up awards, PhD studentships, capital equipment bids. The fund has supported ~£1.8m of research since 2014, now accompanied by the Jansen Family Endowment for Environmental Research (£1.7m).

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Staff are encouraged and supported in compiling grant applications through: (i) bespoke weekly subject-specific email alerts from the RED office highlighting new opportunities and deadlines; (ii) internal sifting and pre-selection of applications for major bid processes; (iii) school-specific compulsory support including early presentation of proposals (e.g. 'chalk talk' presentations, circulated drafts) to colleagues for constructive feedback; and (iv) essential sign-off of applications by senior colleagues acting as pre-reviewers. Success rates are carefully monitored and help target additional support where required. For funding schemes requiring interviews the Faculty offers interview training with a stage performance coach from the Bristol Old Vic Theatre School; this has proven particularly valuable.

2. Infrastructure

UoA5 has benefitted from major University investments specifically within the life sciences field over the period of assessment. Most notably, as described in section 1, this includes £64m for a new hub (LSB) for life sciences research delivering bespoke research and teaching laboratories and greenhouses for bioscience research. This is now fully operational and has been accompanied by renovation and re-housing of much of the Animal Services Unit (£4m) used by many investigators in this unit. This is supplemented by facilities for large animal research (~£3m) at the Bristol Veterinary School located at Langford 12 miles outside of Bristol. There has also been further investment in creating bespoke laboratory space for bioimaging in the building total £600k. In addition, ongoing investment (totalling ~£5m over the assessment period) has taken place in refurbishing laboratories and facilities within the Biomedical Sciences building (in which Biochemistry is located), and £1.6m invested in new communal and social space for staff and students in this same building. Planning is currently underway to replace the Biomedical Sciences Building (houses Biochemistry staff from UoA5) within the next 10-15 years with an estimated £100+m investment.

These substantial infrastructure investments, accompanied by supporting equipment investments described below (see 3c), along with a University-wide £525m capital investment programme described in the REF5a, confirm the strong commitment of UoB to bioscience research for the future.

3. Facilities

With numerous examples cited, UoA5 is highly active in ensuring continued investment in core facilities for Bioimaging, Proteomics, and Functional Genomics. Each of these has been led by UoA5 staff throughout this REF period, driving the intellectual and technological development of these areas across the University. These facilities act as key hubs for research across the UoA with users from all six research clusters. They are also all now established as high profile regional and national resources used by many external researchers. Facility managers for Bioimaging (Jepson and Verkade), Proteomics (Heesom) and Genomics (Edwards (2014-19), now Barker) are research active and returned within this UoA, as are the academic leads. The importance of these facilities to our research is reflected in the significant investment during the review period.

- Over £2.5m of investment has been made in the *Bioimaging Facility*, including extensive redevelopment, acquisition of new technology, and full physical and functional integration of existing light and electron microscopy facilities. Most significantly, this includes acquisition of a *new cryo-EM facility* (£1.5m) which was partly funded by contributions from our GW4 partners together with WT funds to establish this as a regional facility. This has been accompanied by investment in staff appointments (Schaffitzel, plus specialist technical staff). This truly extends the capability of our bioimaging facility from whole organisms and cells right down to true

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molecular resolution. Of note, the cryo-EM provision provides high quality 'local' access with the most demanding samples then being transferred to the cutting-edge Titan Krios scopes at Diamond, which is only an hour away. We are recognised as being at the forefront of implementing new imaging technologies: the Wolfson Bioimaging Facility is now the host of a prestigious European Molecular Biology Organisation (EMBO) course in Correlative Light Electron Microscopy and has acted as a proof of principle site within Euro-Bioimaging, with ambition to become an official node.

- Establishment of the *BrisSynBio Centre* has been accompanied by substantial investment (£1.4m) in automated expression, purification and crystallization facilities, primarily to support structural biology studies although the automated expression facilities have far wider application. These facilities have been supplemented by further investments in large-scale insect cell expression facilities (£1m) and additional crystallization robotics (~£1m).
- Our *Proteomics and Functional Genomics Facilities* have benefitted from updating and extending equipment for quantitative mass spectrometry (~£1m), high-throughput capillary DNA sequencing, high-density-microarray facilities, and next generation sequencers (~£1m) Illumina, Ion Proton, and Ion PGS) enhancing capability in these key areas.
- The *Animal Services Unit* provides outstanding facilities for maintaining model organisms including an extensive and newly equipped zebrafish facility, a new £2.5m aquarium facility for other species, as well as major facilities for rodent and large animal work.
- The *Advanced Computing Research Centre* provides access to HPC for all researchers, along with full training and support. The Centre includes a highly parallelised super-computer facility called BlueCrystal, which is now operating both Phase 3 (serial-optimised) and Phase 4 (parallel-optimised) nodes supporting more than 800 researchers across the University. With ~£12m investment to date, UoB has committed £2m every year to meet the increasing demands of AI, big data and simulation resources across the University. An additional funding boost via a £1m Catalyst award from Hewlett Packard Enterprise aligns with the UoB-led GW4 Isambard project, awarded £4.1m by EPSRC in 2020 and has brought a new ARM-based Tier 2 high-performance computing service to UK-based scientists. This underpins important work in molecular modelling, proteomics, bioinformatics, and synthetic and systems biology.
- The *Research Data Storage Facility* provides integrated resilient, long-term peta-scale storage to all researchers ensuring best practice in data management and sharing including through allocation of a permanent digital object identifier for data sets.

4. Collaboration and contribution to the research base, economy and society
1. Interdisciplinary research within the University of Bristol

The key role of the URIs and examples of how they promote interdisciplinary research and impacts have been described above (Section 1) and in the REF5a. Interdisciplinary working is universally embedded in our working methods and this integration is reflected by joint appointments of staff submitted to other UoAs (Gibson, Vinther, Wall, Rands, Woolfson). UoA5 staff have driven several University-wide initiatives: e.g. Cuthill was a founder of and is on the management board of the Bristol Vision Institute, coordinating research in human and animal vision, machine vision systems, and imaging research. This provides strong links with UoA4 (Cuthill, How, Bok, Roberts), with emerging collaborations in animal cognition (How, Radford, Ioannou, Roberts), and the Bioimaging facility (Stephens, Martin, Verkade, and Jepson). Dynamic Cell Biology and Sensory Biology clusters also have multiple links with photonics and nanoscience groups in Physics (Robert, Roberts, Stephens, Toye, and Whitney). Berger is a Director and founder of the MPI/Bristol Centre

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for Minimal Biology in addition to BrisSynBio. Foster is currently the Director of the Centre for Agricultural Innovation and many staff are involved with different doctoral training programmes across multiple UoAs, for example with the BCFN CDT. Brady, Cullen, Grierson, Martin and Tavaré have been Directors of doctoral training programmes in the assessment period.

An analysis of the research links between this UoA and other Schools reveals not only the high volume of collaborative research, but a diversity of connections. Thus, there are collaborations with Chemistry on proteomics, enzyme structure and function, and synthetic biology (notably Anderson, Bailey, Brady, Race and Verkade), with Mathematics on economic modelling of behaviour (Cuthill) and mathematical, agent-based and network modelling of biological systems with Engineering Mathematics (Grierson, Savery), with Physics and Psychological Science on camouflage (Cuthill), and with Computer Science, via bioinformatics development (Barker, Beaumont) and artificial vision (Cuthill, Roberts). Other activities exemplify how the strategic organization of the unit with fluid boundaries allows rapid developments in new priority areas, for example Brady, Sessions and Verkade have been integral to synthetic biology work within Chemistry (with Woolfson); close links with clinical colleagues are also evident (e.g. see outputs by Nobes, Adams, Frayne, Race, Martin, Cullen, Toye, Lane, and Toye).

2. National Collaborations

These are extensive at the individual level and too many to list (evidenced by ~90% of submitted outputs co-authored with external authors, national and international). This UoA continues to be proactive in coordinating major regional funding bids, particularly through a formal alliance (GW4). Key examples of this cooperation include the BBSRC doctoral training programme (SWBio), Food Security Land Research Alliance and the Cryo-EM Facility all of which span multiple institutions to unite individual research strengths and maximise cross institutional working and cross-disciplinarity with each member organization. UoB is also a BBSRC strategic partner university which informs strategy and planning in both directions.

3. International Collaborations

These activities lead directly to full engagement with external collaborators worldwide. The effectiveness of our extensive network of national and international collaborations can be evidenced by approximately half of our submitted publications featuring non-UK based co-authors from ~30 countries (e.g. Savery with Paris (*Nature*), Jucker >10 countries globally (*Nature*), Szczelkun with Vilnius & Dresden (*PNAS*), Martin with Aarhus and Copenhagen (*EMBO J*), Radford with Canada & Australia (*Nature Comms*), Sessions with Yale and University of California-San Francisco (*Nature SMB*)). UoA5 researchers are also pro-active in establishing international research networks such as the *CONNECTED* network for cassava disease management (Foster), and others have been recipients of UKRI Fund for International Collaboration awards (e.g. Stephens with Kyoto, UKRI-JSPS).

We engage directly with multi-national industry, for example through links to AstraZeneca and Glaxo SmithKline for pharmaceutical work, Oracle for advanced cloud-based computing, and Leica Microsystems and FEI for microscopy. Our Bioimaging Facility has been pro-active in the organization of both UK and European future strategies for Bioimaging infrastructure which have fed directly into UK and EU funding agency programmes.

4. Contribution to the discipline

UoA5 staff make leading contributions to their respective fields in various ways:

Journals

All submitted staff are actively engaged in essential discipline activities such as peer reviewing for journals and grants panels. UoA5 staff serve as Editors or editorial board members of >40 broad biology or specialist journals (for example: Adams Editor-in-Chief *AJP-Cell Physiology*, Hetherington Editor-in-Chief *New Phytologist*; Editorial Boards: Dillingham (*Biochemical J*), Lane (*Autophagy*), Mogessie (*Hu Mol Repro*), Stephens (*J Cell Sci*, *bioRxiv*, *Review Commons*) Cuthill (*Proceedings of the Royal Society B*) Hetherington (*New Phytologist*).

Membership of grant and fellowship awarding bodies

Many members of the unit serve on and chair major national and international grants panels as well as strategy and advisory boards. Examples include the ERC (Berger, Szczelkun), UK Research Councils/UKRI including BBSRC (Stephens, Chair of BBSRC Committee D and now BBSRC Council member; Roberts, Deputy Chair of BBSRC Committee E) and MRC (Tavaré, Chair of MRC Non-Clinical Fellowship Panel, Deputy Chair (2015) and Chair (2021) of MRC DTP Panel), Collinson, Dodd, Franklin, Grierson, Stephens, Szczelkun, Verkade, and Martin have been members of other UKRI Committees, REF2014 & REF2021 (Brady), WT (Banting, Martin, Cullen (Deputy Chair ERG7)), CRUK (Martin), Juvenile Diabetes Research Foundation and Diabetes UK (Tavaré), Parkinson's UK (Lane), NC3Rs (Cuthill) and Royal Society (Adams, Anderson, Cuthill, Dillingham, Mellor, Race).

Committee membership of professional bodies, charities and trusts

During the review period members of UoA5 also served as trustees or board members of professional societies (including Adams, Brady, Cullen (FMedSci), Cuthill, Dillingham, Grierson, Hanley, Hetherington, Holderied, Kuwabara, Lane, Martin (FMedSci), Mellor, Memmott, Nobes, Roberts, Savery, Stephens, Tavaré, Verkade). Memmott is President of the British Ecological Society and Martin is Chair of the British Society for Developmental Biology.

Honours, fellowships and other awards

The unit prides itself on attracting many ECRs in receipt of prestigious fellowships. These have included both past (now permanent) and present awardees Anderson (RS URF), Bauer (RS URF), Curnow (BBSRC DPF), Baldock (NERC Knowledge Exchange Fellowship), Carroll (WT), Chambers (CRUK), Dodding (Lister Fellow), English (RS Dorothy Hodgkin), Franklin (RS URF), Gorochowski (RS URF), Harrison (RS URF), How (RS URF), Jucker (NERC IRF), Ioannou (NERC IRF), King (Branco Weiss), Mogessie (WT), Montgomery (ERC Starter and NERC IRF), Race (RS URF), Stroeymeyt (ERC Starter), Sutton (RS URF), Weavers (WT), Williams (RS URF). Overall, more than 80% of these fellowship awardees have progressed to permanent positions at UoB.

In addition, senior staff regularly win competitive fellowship awards such as (Senior) Investigator from the WT (Berger, Collinson (former Colworth Medal), Cullen (x 2), Dillingham (former Colworth Medal), Martin and Schaffitzel), ERC Advanced Awards (Szczelkun, Robert) and ERC Consolidator Award (Radford). Cullen and Martin have been elected as Fellows of the Academy of Medical Sciences. In 2020 Jucker received the prestigious British Ecological Society Founders' Prize, Ioannou the Fisheries Society of the British Isles (FSBI) medal and Cullen was awarded the Royal Society Noreen Murray Professorship.

These interactions with our research collaborators, other Universities, professional societies, industry, charities, and governmental agencies ensure that our research has impacted on and

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continues to contribute substantially to research outcomes, policy-making and strategy at national and international levels.