Institution: University of Cambridge

Unit of Assessment: 12 - Engineering

1. Unit context and structure, research and impact strategy

Materials Science and Metallurgy (DMSM), Chemical Engineering and Biotechnology (CEB), and Engineering (CUED) are independent departments within the University of Cambridge (UCAM). CEB and CUED are in the School of Technology (SoT); DMSM is in the School of Physical Sciences (SPS). This is the first time that the three departments have made a joint REF submission.

Collectively, UoA12 has a thriving research culture. We connect and collaborate with many UCAM departments and with companies and government, both regionally and internationally, and host many internationally-leading research groups. There are 204 permanent academic staff (DMSM 27, CEB 29, CUED 148), 400 postdoctoral researchers and 1320 postgraduate research students (populations current at close of REF period). Additionally, a continuously-cycling population of ~50 independent Research Fellows enrich the environment with their talent and bring new research directions. Retirements within the REF period have given opportunities to refresh and diversify research portfolios and to appoint early-career researchers (ECRs) embracing gender and racial diversity. The research culture across the departments promotes strong collaborations with other disciplines, institutions and industry, whilst maintaining a powerful presence in fundamental science and engineering. A particular priority is tackling global challenges, e.g. climate change, energy transition, zero-carbon aviation, healthcare, modern manufacturing and third-world development.

Our future strategy has identified goals to be pursued jointly, whilst capitalising on the disaggregated departments to initiate novel, fundamental research. The sections of this Environment Statement are structured thus

- where relevant, a general section covering common practice,
- details of individual departmental practices to give exemplification or where different specific approaches are taken, and
- commentary, where applicable, on plans across the UoA to build further capacity and impact.

1.1 Structure of Departments

DMSM

Structure

DMSM aims to conduct research at the highest international level in the materials discipline. It has 27 academic posts, 11 Research Fellows and other independent researchers, 40 PDRAs and 140 postgraduate research students, supported by 48 technical and administrative staff.

DMSM is proud of its record in rearing the leaders of the future, through mentoring at all stages to promote career progression, leading ultimately to distinguished appointments worldwide (see §2).

The Head of Department (HoD) is supported by two Deputies (DHoD), one focused on research, the other on education. The DHoD Research chairs the Research Committee and, with the HoD,

is responsible for developing DMSM's research profile, formulating strategy and policy: including research integrity, safety and ethics, open research, research engagement and, through the Graduate Education Committee, postgraduate researcher development. The Research and Business Development Manager supports academic staff in establishing and maintaining external industrial relationships, managing contractual and IP agreements, and developing entrepreneurship and impact.

Research Themes

Research is organised in to seven strategic areas:

*(i) Aerospace Materials***.** Activity encompasses the engine and airframe, and component manufacturing methods. Research is led by the *Rolls-Royce University Technology Centre*, hosted within DMSM and one of two such UCAM centres (the other in CUED, described below). DMSM also leads an EPSRC/Rolls-Royce Strategic Research Partnership, linking seven universities and three other departments in UCAM.

(ii) Novel Design and Processing of Materials. Understanding the processing-property-structure linkage differentiates DMSM from other UCAM STEM departments. The activity spans all materials types and functionalities and all industry sectors, from ICT to transport to medical, and is well aligned with UCAM's Interdisciplinary Research Centre (IRC) in cardiovascular problems, as well as with the UCAM spoke of the national Royce Institute and the *EnergyTransitions@Cambridge* Interdisciplinary Research Centre (IRC). There are many company and institute links, e.g. Rolls-Royce plc, Ilika plc, Meggit plc, EMPA (Switzerland), MPIE (Germany), including several medical manufacturing companies.

(iii) Innovative Characterisation of Materials. DMSM is at the forefront of characterisation by combining complementary techniques, drawing on latest equipment and data-analysis to gain deep understanding of the structure and properties of materials, e.g. novel alloys, soft collagen scaffolds, luminescent semiconductors and hybrid organic-inorganic devices. The internationally-leading Wolfson Electron Microscopy Suite (in purpose-designed 2013 building) has enormously benefitted from the purchase of advanced instruments (§3.5, §3.6).

(iv) Materials for Energy. This covers materials for novel energy-conversion and storage technologies, e.g. innovations in lithium-based storage devices and new techniques to manufacture and study GaN-based materials for efficient lighting and photovoltaics. DMSM's success in commercialising developed technologies is evident from its industrial partnerships (e.g. Plessey, Solaris, Cambridge Display Technology and Murata), and its generation of spin-out companies. The £2.1M EPSRC *Network Centre for Advanced Materials for Integrated Energy Systems* (UCAM, Newcastle, Queen Mary, UCL) provides a collaborative platform to identify future synergies with other EPSRC Centres, industry and stakeholders.

(v) Materials Discovery. Research ranges from synthesis of new compounds and design of superalloys, to theoretical modelling and computational prediction of new materials. First-principles, predictive, computational techniques play increasing roles in exploring and rationalising material properties; DMSM has led in benchmarking methods and codes. The work is supported by the UK Car-Parrinello Consortium providing access to national supercomputing facilities. DMSM has developed (with UCAM Physics) the CASTEP and NMR-CASTEP codes, freely available to the UK research community, and widely-used commercially; CASTEP is one of our Impact Case Studies.

(vi) Materials for Healthcare. This aims to optimise the efficacy of medical interventions and drug-delivery devices through a combination of cell biology and innovative development of novel

materials and structures. The strong linkage with clinicians, biologists, biochemists, physicists and engineers includes, e.g., the development of novel tissue engineering materials and structures for optimised tissue repair. The area also encompasses pharmaceutical materials science, e.g. numerical simulation of powder compaction. DMSM work has resulted in national and international collaborations, industrial sponsorships and licensing.

(vii) Materials for Information Communication Technologies. This addresses the need for new materials that are fundamental to innovation, performance, and energy efficiency for both low-power (portable appliances) and high-power (data centres) uses. Research is focused on development of superconductor/ferromagnet devices for low-temperature logic devices, oxide heterostructure systems for data storage, novel magnetic and spintronic materials systems, and single-photon devices for optical communication. This theme aligns directly with the UCAM hub of the Royce Institute focused on Materials for Energy-Efficient ICT (§4.2).

CEB

Structure

CEB is a multidisciplinary department creating innovation at the interfaces between chemical engineering and fundamental sciences. It has 29 academic posts, 7 Research Fellows and other independent researchers, 43 PDRAs and 203 postgraduate research students. Research is supported by 46 FTE technical and administrative staff. CEB is housed in a new £60M building (see §3.5).

The HoD is supported by deputies in research and teaching. The DHoD Research leads the Research Committee and, with the HoD, is responsible for developing CEB's research strategy and policy, research integrity, safety and ethics, open research, research engagement and, through the Graduate Education Committee, researcher development. Departmental strategy and impact are reviewed, and informed, by an external advisory board of senior academics from other universities, and professionals from industry and national bodies.

Research Themes

CEB research strategy builds on its cross-disciplinary culture, with core competencies in (i) materials, (ii) sensors and diagnostics, and (iii) process and reaction engineering. The overall strategy is based on belief that by understanding the underlying principles and engaging in the fundamental science upon which a phenomenon is based, innovative solutions to important problems in the fields of *health* and *sustainable manufacturing* can be developed, having societal, environmental and economic impact.

(i) Materials. For *health*, materials research in CEB is focused on predictive modelling, synthesis, modification and full characterisation of novel medical materials to be used as drugs or as medical devices. There is substantial expertise in the manufacturing and analysis of solid-dosage pharmaceuticals. Current activities in targeted drug delivery utilise porous materials (metal organic frameworks (MOFs)) and biopolymer/liposome/spore composites to tackle intractable cancers and senescent cells, using external guiding systems based on light, magnetic field or novel acoustic technologies. Acoustic strategies for drug delivery have been developed, e.g. for the controlled delivery of a drug to prostate cancer cells. Other research has investigated targeted delivery strategies for DNA and viral therapeutics using liposomal formulations and cell-penetrating peptide design. CEB also develops biomimetic biological models with integrated electronic devices

(organs-on-chip) to enable drug screening using artificial systems predictive of real biological environments.

Medical materials for tissue engineering and tissue repair such as polymeric heart valves and calcium phosphate pastes for vertebral repair have been developed in collaboration with clinicians to enable direct translation to medical applications.

For *Sustainable manufacturing,* materials research concentrates on sustainable processes, e.g. catalysts for the low-temperature production of hydrogen from ammonia under conditions relevant for fuel cells. Effort also targets replacement of noble metals (mainly ruthenium) by readily-available ones, including bi-metallic systems. Chemical-looping approaches are being developed for safer selective oxidation reactions, e.g. manufacture of ethylene oxide, using novel combinations of catalyst and oxide support. Substantial research in MOFs targets gas storage and adsorbents for CO_2. Spin-out companies have resulted from chemical-looping (*Inert Gas* Impact Case Study) and MOF work.

(ii) Sensors and Diagnostics. For sensors in *health*, research on the synergy of advanced proteomic/genomic technologies, imaging and biosensor technologies tackles questions in neuropsychiatric and neurodegenerative disorders and intractable cancers. For example, newly developed optical super-resolution techniques can follow protein translation events at the single-molecule level, with significant impact for the study of neurodegenerative diseases. Medical diagnostics for low- and middle-income countries, exploiting synthetic biology to develop sensors for malaria diagnosis, have been trialled in Ghana and Malaysia (2019).

Newly developed Terahertz imaging significantly advances the study of solid-dosage forms and secondary pharmaceutical manufacturing. Multi-nuclear, quantitative MRI techniques are used to understand drug dissolution, assisting industry in optimising design pathways for drug-product development and formulation, attracting significant funding from AstraZeneca and Merck.

A focus in sensors for *sustainable manufacturing* is the development of quantitative methods in Nuclear Magnetic Resonance (NMR) spectroscopy to characterise single- and multi-component adsorption and transport directly inside catalyst pore spaces. A highlight is inserting a fixed-bed reactor, at 300˚C and 30 bar inside a 300 MHz superconducting magnet to study Fischer-Tropsch (FT) synthesis. Magnetic Resonance Imaging (MRI) features as an Impact Case Study.

(iii) Process and Reaction Engineering. There are strong interests in the phenomena underpinning *sustainable manufacturing* and the production of clean energy (work on FT was noted above). Fluidisation remains a key topic with current focus on chemical looping for the capture and storage of CO_2 from use of biomass fuels. Fluidisation is also studied using innovative combinations of new (e.g. MRI) and existing (e.g. Particle Image Velocimetry) techniques, underpinned by theory (e.g. Discrete Element Modelling) providing insight into energy-efficient reactors.

Computational research focuses on machine learning and statistics to develop sustainable chemical systems, assisted by 'chemical robotics'. Newly-developed reactor concepts promote the sustainable manufacture of molecules and functional nanomaterials. Detailed models for combustion-generated nanoparticles are developed in collaboration with major engine manufacturers, e.g. Toyota. There is complementary research on turbulent plumes in the environment, and flow and reaction in porous media, e.g. spread of CO_2 in geological storage.

Research on fouling and cleaning in process equipment aims to reduce the carbon footprint and energy consumed by industry, especially oil-refining and food. CEB research forms the basis of the leading software tool in the field (*SmartPM* Impact Case Study).

CUED

Structure

CUED has 148 academic posts, 28 Research Fellows and other independent researchers, ca. 300 PDRAs and 987 postgraduate research students. It is structured organisationally (vertically) by engineering discipline into six academic divisions. Research activities span divisions, with formal and informal structures linking activities horizontally by application domain across CUED. The structure allows pursuit of research excellence across engineering in its breadth, unconstrained by traditional engineering discipline boundaries.

The HoD is supported by three Academic Deputy Heads (Teaching, Graduate Studies, Research), a Director of Strategy and Operations (DSO, also a DHoD) and the Academic Committee. The Academic Committee, chaired by the HoD, comprises the four DHoDs and the six division Heads. The discipline-based divisional structure provides a coherent framework for managing a large department. The HoD and Academic Committee are advised on research strategy and policy by the Research Committee (RC), chaired by the DHoD Research, with a membership of senior academic staff. The RC oversees the implementation of CUED and UCAM research policies, research translation and impact, and ECR support. Postgraduate researcher development is overseen by the DHoD for Graduate Studies.

The divisions (with academic staff numbers) are:

Division-A: Energy, Fluid Mechanics and Turbomachinery (30)

Division-B: Electrical Engineering (24)

Division-C: Mechanics, Materials and Design (25)

Division-D: Civil Engineering (25)

Division-E: Institute for Manufacturing (17)

Division-F: Information Engineering (27).

Research Areas and Themes

Research activity is arranged around ~15 multi-disciplinary areas crossing the six discipline divisions. The number of areas reflects CUED's size and the breadth of research activity. Selected areas include:

Energy. Research investigates energy systems at a wide range of scales, from microelectronics to propulsion and transportation. A strong recent focus is energy storage, electrification and other technical solutions for zero-emission transportation, including high-power-density electrical systems, electro-mechanical properties of materials for energy storage and alternative fuels. The research also supports mitigating the environmental impacts of established technologies through building fundamental understandings of reacting flows, acoustics and turbines (aero, wind and tidal). CUED Centres involved in energy research include the Whittle Laboratory, the University Gas Turbine Partnership (supported by Rolls-Royce) and the Centre for Doctoral Training in *Future Propulsion Technologies*. There is alignment with the *EnergyTransitions@Cambridge* IRC, and strong industrial engagement, e.g. Rolls-Royce, Mitsubishi Heavy Industries and Siemens (see two Impact Case Studies on turbomachinery).

Materials. Research spans: nano-scale and electronic materials to micro-architectured materials and to bulk construction materials. Common to research at all scales is building fundamental insights and using new understanding to develop models for material behaviour supporting new

engineering applications, the creation of new engineered materials, and new materials processing technologies. Application areas include functional and layered materials, materials for communications, flexible electronics, biomaterials, nano- and micro-engineered materials and self-healing construction materials. CUED Centres engaged in materials research include the *Cambridge Graphene Centre*, the EPSRC programme grants *Resilient Materials for Life* and *LightForm: Embedding Materials Engineering in Manufacturing with Light Alloy* and the *Advanced Nanotube Application and Manufacturing Initiative*. CUED operates shared materials-research facilities for the Royce Institute.

Bioengineering and healthcare. Research includes quantitative neuroscience, tissue and organ engineering and theoretical and experimental investigations of how biomaterials, from cells to skin, bone and muscles, respond to mechanical and other stimuli. Fundamental insights into biological systems are developed to create engineered solutions for health and wellbeing. Healthcare research includes diagnostic and therapeutic technologies and systems approaches to healthcare delivery. CUED Centres include the EPSRC Interdisciplinary Research Collaboration in *Targeted Delivery for Hard-to-Treat Cancers,* the EPSRC NetworkPlus *Fast Assessment and Treatment in Healthcare* and the *Cambridge Centre for Engineering Better Care*, a collaboration with the School of Clinical Medicine. Research in bioengineering and healthcare is often undertaken in close collaboration with clinical and biological-sciences researchers.

Environment. This includes technical and policy research. Technical approaches include carbon capture, environmental fluid flows and air quality modelling and sustainable transport. Policy research is underpinned by quantitative engineering analysis. Research in the environment area overlaps considerably with other themes, including materials (e.g. low-carbon materials, energy-storage technologies) and energy (e.g. renewable energy generation, emission reductions in conventional energy generation, novel propulsion systems). CUED's major initiatives include the EPSRC Programme Grant *UK FIRES: Locating Resource Efficiency at the Heart of Future Industrial Strategy in the UK,* the EPSRC *Centre for Sustainable Road Freight* and CUED contributes to UCAM's *Cambridge Zero* initiative and *EnergyTransitions@Cambridge* IRC.

Cities and infrastructure. This area addresses policy, digital and data science, resilience of infrastructure, construction materials, construction technologies and transportation. Research focuses on new technologies underpinning the development and maintenance of resilient infrastructure, and the enabling of safe and cost-effective developments in increasingly crowded and challenging construction environments both above and below ground. CUED Centres supporting research and external engagement in this area include in the *Schofield Centre* for geotechnical research, the *Laing O'Rourke Centre for Construction Engineering and Technology*, the *Cambridge Centre for Smart Infrastructure and Construction* and the Centre for Doctoral Training in *Future Infrastructure and Built Environment.* Research in this area engages closely with the UCAM-based *Centre for Digital Built Britain*. The Impact Case Study on Smart Infrastructure followed from research and industrial collaboration in this theme.

Intelligent systems. Research spans from theoretical foundations of machine learning and inference to autonomous systems, analysis of highly connected systems, robotics, language processing and applications of machine learning and AI to physical engineering systems. CUED's unique strength in this area is the breadth of expertise with research leaders in theory and fundamentals through to advanced applications (e.g. robotics, autonomous vehicles, materials discovery, data analytics of cities and infrastructure). Latest theoretical developments in machine learning and AI are adapted to challenging engineering applications, and engineering applications drive new theoretical developments in machine learning and AI. CUED is a partner in the UKRI Centre for Doctoral Training *Application of Artificial Intelligence to the Study of Environmental Risks*. There is close alignment with the *Cambridge Centre for Data-Driven Discovery*. Several

staff members are affiliated with the *Alan Turing Institute.* Close links exist with numerous companies, including Microsoft Research and Toyota.

Management and policy. Research includes how businesses can manage and exploit changes driven by technology advances, including supply chain management, intellectual property management and digitalisation, and how government policy can impact on productivity, international competitiveness and resilience. Research is highly collaborative, and frequently undertaken with colleagues at the Cambridge Judge Business School, and with businesses through centres at CUED including the *Cambridge Service Alliance,* the *Strategic Technology and Innovation Management Consortium* and the *Digital Supply Chain Consortium*. Research interactions with wider UCAM include the *Cambridge Global Food Security* IRC. Research in this area led to the Impact Case Study *Roadmapping for Strategic Technology and Innovation Management*.

1.2 Research Strategy

A distinguishing feature of research across the UoA is recognition of the underlying strength in curiosity-driven research, promoted in synergy with strategic initiatives that build activity, capacity and collaboration in identified areas. The Departments' research strategies support and encourage innovative, curiosity-driven research at the highest international level. UCAM has a long history of academic-led, ground-up research. This has led to successful research and innovation that builds on the strength and ambition of the academic staff. There is emphasis on consultative structures within departments to build strategies by consensus, underpinned by the highest-quality research staff. There is wide consultation with external advisory bodies.

1.2.1 Departmental-Based Research Strategy

The **overall aim** of the Departments is to conduct the highest-quality research in a vibrant, multidisciplinary environment, which shapes and defines the future direction of engineering and materials science. The Departments are, collectively, exceptionally placed to support multi-disciplinary research through the breadth of expertise in the UoA, and through strong links to other departments in UCAM, elsewhere in the UK and internationally.

DMSM

The **strategy** is to: (i) prioritise research quality in staff appointments, (ii) maintain a broad portfolio rooted in the research areas (listed in §1.1), while ensuring each remains of critical mass, (iii) build on this breadth to initiate cross-disciplinary efforts in DMSM and to establish best-with-best national and international collaborations, (iv) maintain diversity of research income. DMSM's Research Committee (RC) overviews research strategy and launches initiatives. RC decisions are informed by DMSM and research-group strategies and Government policy.

Regarding **strategy development and review**, DMSM's research portfolio is reviewed regularly with internal and external input. The RC is the primary internal source of consultation and recommendation, supplemented by biennial 'awaydays' where major issues are debated. Following a UCAM Strategic Research Review in 2018, DMSM prioritised growth initially in computational materials science, enabled if required by proleptic appointments.

CEB

A key objective is to translate sustainable practice into industry, academia and policy, promoting exploitation of innovations from research in industry or spin-out companies. The **strategy** is to: i) recruit and retain world leading research staff in key areas of interest, ii) provide world-leading research infrastructure, iii) maintain a diversified income portfolio, including a mix of industrial and Government funding, iv) provide research and leadership training to generate responsible leaders in academia and industry.

Research strategy is developed around its cross-disciplinary culture and builds on core competencies in (i) materials, (ii) sensors and diagnostics, and (iii) process and reaction engineering. It is implemented by the Research Committee, headed by the DHoD for Research and comprises an inclusive cross-section of academics (6M, 4F from PDRA to Professor), meeting termly and liaising closely with the HoD and the Department's external communication officer.

CEB's research portfolio was reviewed by an international expert panel during a UCAM Strategic Research Review (SRR) in 2018, which reaffirmed its strategy but recommended a restructuring of technical support, which was completed in early 2020. Members of the SRR panel serve on an external advisory board invited every 2 years to advise on CEB strategy. Further advice is sought in annual meetings with industry partners and national bodies (AstraZeneca, Shell, BP, Schlumberger, TATA, Nokia, DEFRA, NPL).

CUED

The **objective** is to benefit society by creating world-leading engineering knowledge that fosters sustainability, prosperity and resilience. By ensuring integration across its disciplines, CUED addresses major challenges and develops complete solutions. Sustainability has been central to strategy since 2009. Key to achieving our strategic aims are (i) recruitment and retention of internationally outstanding researchers, (ii) actively maintaining a cohesive and broad research profile to deliver integrated solutions to major scientific, industrial and societal challenges; (iii) building the necessary capacity in new strategic research areas to have major research impact, and ensuring that capacity is maintained in established areas with continuing high research potential and (iv) maintaining balanced income streams (Government/industry/ charity/philanthropy) to underpin and support core objectives. Strategic initiatives are supported through: (i) academic appointments in areas identified for strategic growth; (ii) events to attract academics from across the divisions to develop research plans in strategic areas; and (iii) seed funding to build activity and capacity in identified areas.

Regarding **strategy development and review,** the HoD and the Academic Committee are advised by the Research Committee in development, review and implementation. Review of research strategy occurs regularly and is informed by (i) bottom-up consultation with academic staff at all career stages, (ii) engagement with, and response to, UCAM strategic developments, and collaborative initiatives with other departments, (iii) global trends and the directions, needs and priorities of research sponsors (government, industry and charities), and (iv) review every 2-3 years by the International Visiting Committee. The ~15 research areas/themes that are used to frame research activity across CUED are reviewed annually by the Research Committee. Strategic development is driven by decisions to expand or intensify research activity in identified existing or new areas. Strategy is implemented through new appointments and/or supporting Department-wide working groups and other initiatives to build and establish capacity. Recent examples of expanded activity in the *bioengineering and health* area following targeted support include:

- *Cambridge Centre for Engineering Better Care*, a UCAM-funded collaborative centre led by PIs from CUED and the School of Clinical Medicine. This includes office space and laboratories on the Biomedical Campus. The *Cambridge Public Health IRC* and the Centre for Engineering Better Care are embedded in CUED.
- *Institute for Neuroscience*, a collaboration amongst departments including Physiology, Development and Neuroscience, Psychology, CUED, Applied Mathematics and Theoretical Physics and Physics, funded by UCAM.
- The £10M EPSRC Interdisciplinary Research Collaboration in Targeted Delivery for Hard-to-Treat Cancers, led by CUED, started in 2018.

CUED contributes to research strategy development in the SoT and UCAM, and in the wider national and international communities by encouraging and supporting staff in public engagement and through membership of industrial, Government and charity technical and policy boards.

1.3 Research Impact Strategy

Natural routes to impact are formed by the highly-supportive industrial partners collaborating with each Department. Additionally, commercialisation of research outputs via spin-outs and entrepreneurship is supported by the Departments and wider UCAM with professional support from Cambridge Enterprise (CE) and financial support from CE Seed and UCAM Enterprise Funds. The Departments also benefit from the highly-networked enterprises located on the science parks around Cambridge, supplemented by substantial collaboration beyond UCAM. The benefits of Science Park enterprises are that they employ graduates and consultants from UCAM, they use high-specification experimental facilities (e.g. hosted by the Royce Institute) and present important areas for research.

DMSM

Departmental environment and ethos encourages close relationships between academic staff and leading industries. Links with industry are developed and strengthened, and research impacts are promoted, by a dedicated Research and Business Development Manager. DMSM works with ~40 companies, prioritising transfer of technology and wealth creation through e.g. spin-out companies (12+ established since Jan 2014) including *CamSES*, *Paragraf*, *Cynergytec* and *Kubos Semiconductors*. A longer-term spin-out, *Inotec IMD*, is included in our Impact Case Studies. CE holds weekly surgeries dedicated to meeting members of DMSM. Students and PDRAs are encouraged to participate in UCAM-wide activities to provide training: *i-Teams*, *Impulse Programme* (Maxwell Centre), *Accelerate Programme* (Judge Business School), and events run by the *Cambridge University Technology & Enterprise Club*. The *Postdocs of Cambridge Society* and CE run a business-plan competition: in the last five years, four finalists have been from DMSM, with Dr Tongtong Zhu winning the first prize and establishing spin-out *Porotech* which has raised £1.5M seed funding to commercialise high-efficiency GaN LEDs.

CEB

More than 40 companies benefit from CEB's staged engagement model, offering collaborative projects that range from pilot study to fully funded research programme. Engagement ranges from short proof-of-concept studies (e.g. Alphasense, Fluidic Analytics, Galvani, etc.) to full-scale collaboration (e.g. AstraZeneca, Johnson Matthey – see MRI Impact Case Study, Shell,

Schlumberger, Infinitus). Active links are maintained with industry through consultancy and funded research programmes. CEB hosts biweekly industry lunch talks and engages a professional research facilitator to match needs with skill. Commercialisation of research outputs via spin-outs and entrepreneurship is encouraged with support from Cambridge Enterprise. Recent spin-outs from CEB include Computational Modelling Cambridge Ltd, Immaterials Ltd and EnVal. CEB's impact strategy is informed through close links with national research bodies and government departments, including the National Physics Laboratory, British Antarctic Survey, the Centre of Global Equality, and DEFRA, who provide members for our advisory board. CEB academics are encouraged to serve on boards, with one (Gladden) serving as executive chair of EPSRC.

CUED

CUED supports and fosters strong relationships involving academics, industrialists, policy makers, governments and charities, and provides support and training on the translation of research developments into practice. It maintains long-term research partnerships with several major sponsors (including Rolls-Royce plc, Mitsubishi Heavy Industries, Boeing, Dyson, Laing O'Rourke), thereby stimulating novel research in response to emerging industrial challenges and facilitating effective and rapid knowledge transfer and impact through close collaboration. The Impact Case Studies on the *S-duct* and *Compressor Leading Edge* with Rolls-Royce, and the ICS on *Smart Infrastructure* with close engagement with research sponsors, are examples of impact through partnership. CUED hosts embedded industrial researchers from a wide range of sectors to engage in collaborative research and support research impact, with 136 embedded industry researchers hosted over the assessment period (82M, 54F). Academic staff are supported (e.g. by counting major activities as part of their teaching and administration duties) in taking up industrial/governmental technical and policy advisory board/panel roles to promote both industrial and social impact (see indicators in §4). *Institute for Manufacturing Engage* (IfM Engage) is a wholly owned subsidiary of UCAM to provide consultancy, professional development services and training based on research developed at the IfM and CUED. IfM Engage works with a wide range of policy and Government bodies, large companies and SMEs, providing a variety of training courses. IfM Engage consortia and training programmes support the translation of research developments into practice, including supporting organisations implementing *Roadmapping* (see Impact Case Study) and developing new supply chain networks. At CUED, relationships with industry and the translation of research into application were strengthened by hosting seven RAEng Visiting Professors of Innovation over the assessment period. The development of new external strategic relationships is supported by the Director of Strategy and Operations.

1.4 Open Research Strategy

Common Departmental Approach

All Departments follow the UCAM Open Research Policy, and support academics in meeting the policy requirements and ambitions, aided in turn by working approaches developed by the Schools of Technology and Physical Sciences. Open research strategy in each Department is overseen by the Research Committees and the DHoDs (Research), with support since 2019 of a dedicated Research Librarian in **CUED** and **DMSM**, and by the Business Development Manager in **DMSM**. The support for open research includes advice on IP management, (open) licensing and data management with the goal of being as open as possible. Research proposal, Data Management and Sharing Plans are reviewed by the Research Offices in each Department to assist academics in developing plans that meet legal and integrity requirements. For industrial sponsors emphasis is put on the benefits of open research and agreeing to UCAM retaining IP rights over funded

outputs. This allows the Departments to manage and promote the open sharing of results and IP. Sponsors allowing UCAM to retain IP rights are charged at a discount relative to sponsors insisting on retaining IP rights. The release of research software under open-source licences is supported; this enhances the accessibility of the research and promotes reproducibility. Within the assessment period, cases were made successfully to major industrial sponsors (including Mitsubishi Heavy Industries, Toyota and Rolls-Royce) to support development of open-source research software.

The Sensors CDT provides formal training to scientists across the UoA (and to 18 other departments in UCAM) on hardware technologies for research (e.g. use of Raspberry Pis in scientific instrumentation, development of rapid prototyping skills and open sharing of 3D print designs, use of open-source software tools such as Python and Micromanager, etc.). Researchers and early-career PIs also receive public engagement training, e.g. through participation in the yearly *Team Research Challenges*, which engage citizens in large-scale research projects. For example, *OpenSeneca*, the 2018 Team Project, developed a citizen-science portable air-quality monitoring system for bicycles. This network now has global nodes with worldwide participation.

Commentary on the UoA

There is a commonality of approach, largely informed by evolving UCAM policy in the area (particularly around the details of research data management and open data access) informed by the Research Committee/Council of the two Schools. A good example of joined-up vision and strategy is the OpenVentilator initiative: https://www.cam.ac.uk/research/news/open-source-ventilator-designed-by-cambridge-team-for-use-in-low-and-middle-income-countries.

This pooled resources and skills from CUED, CEB, DMSM and industry to produce a prototype ventilator for Covid-19 patients in low- and middle-income countries – an exemplar of our ethos of making technology open and available to those who need it. Further developments will be monitored by the two Schools, via DHoDs (Research), who will support evolving requirements and implementation.

1.5 Research Integrity and Ethics

Common Departmental Approach

Each Department follows the Universities UK *Concordat to Support Research Integrity* and incorporates the *Concordat* into its research strategy and training for existing researchers and at induction. In each Department, implementation of the *Concordat* is overseen by the DHoD (Research) and the Research Committee. In CUED, the DHoD and the Director of Strategy and Operations promote implementation with support from the CUED Library. In CUED and CEB, further assistance comes from the School of Technology Research Committee, with direct links to UCAM's Research Policy Committee, ensuring that latest developments are taken up. As noted in §1.3, **CEB** has devised a new taught module for PhD researchers, open also to students in CUED and DMSM, on Responsible Research and Innovation, covering ethics and integrity, inclusive research leadership and responsible entrepreneurship.

In **CUED** the ethics of research with human participation is overseen by the CUED Research Ethics Committee, with proposed research following a 4-stage review process. Low-risk activities are approved following (i) self-assessment and (ii) consideration of the research and self-assessment by a divisional member of the Ethics Committee. Higher-risk activities are considered by (iii) the full Ethics Committee, which can (iv) refer to a specialised review panel at another department or at UCAM level. The Committee reports annually to the UCAM Research Ethics Committee. Proposed research involving animals must be referred directly to UCAM's Biomedical

Support Services and CUED's Ethics Committee is informed. For collaborative research, e.g. with the Clinical School, approval may be handled by other ethics committees in UCAM.

All research involving human tissues is conducted under NHS Research Ethics Committee approval. Potential use of personal data is first discussed with the Secretary to the Department who arranges for review by the appropriate Ethics Committee within UCAM. All Departments are fully compliant with the Human Tissue Act 2004.

The Departments take all steps necessary to provide a healthy and safe environment. Compliance with all statutory obligations is the minimum standard. To fulfil this commitment, each Department implements the health, safety and welfare policies of UCAM and supplements them with local departmental policies and guidance as necessary. Each HoD has ultimate responsibility for ensuring the health and safety of all staff, students and others using, or working on behalf of, the Department, supported by DHoDs, Academic Supervisors, line managers, Departmental Safety Officers and specialist Biological, Laser and Radiation Safety Officers and UCAM's Safety Office. The formulation and review of Departmental health and safety policy, guidance and the monitoring of health and safety requirements, implementation and performance is the responsibility of the various Departmental Safety Committees, chaired by the respective HoD.

1.6 Achievement of Planned Aims in the Assessment Period

DMSM

In REF 2014, DMSM identified **3 main aims**, each achieved.

1. *To appoint an internationally leading scholar to the Cottrell Chair.* Professor Chris Pickard was appointed in 2015 to lead research in computational materials science and materials discovery.
2. *To develop industrial collaboration in the context of the Maxwell Centre.* Since 2014, DMSM has been a fully engaged partner in the Maxwell Centre, UCAM's West Cambridge hub to facilitate interactions between industry and academia. Over the assessment period, DMSM has housed 12 researchers in the Centre including **Rivera** (now Professor at Lancaster University). DMSM continued to develop collaborations with industrial partners since 2014 including, e.g. the completion of an SKF centre, based at the Maxwell Centre, leading in part to a new collaboration with Ovako, based at the Maxwell Centre but working with instrumentation and staff within DMSM.
3. *To continue academic staff renewal by appointments at international level.* In addition to the Cottrell Chair, DMSM has made 10 appointments of outstanding internationally-leading academics, including the Goldsmiths' Chair, who has initiated new research in low-dimensional materials. Lectureship appointments cover a broad spectrum of materials science: device materials, high-strength alloys, photovoltaic materials and polymer-based nanomaterials for energy harvesting, computational materials science, and a fixed-term lectureship to support the RAEng Chair in oxide materials. In addition, two lectureship appointments are jointly with Physics and Earth Sciences, in high-power semiconductor materials, and in materials characterization. A Royal Society URF was hosted to establish a new theme in glassy metal-organic frameworks and two RAEng Research Fellows working on novel steels and alloys, and novel photovoltaic materials.

CEB

In REF 2014, CEB identified **3 main aims**, each realised.

1. *Capitalise on opportunities presented by the move to a new building.* The prime objective during the assessment period was to seize opportunities presented by the new building to house all CEB research on one site at West Cambridge. The building adopts an inspirational design promoting the interdisciplinary interface and the flexible research clustering that has been a strength to date. State-of-the-art bespoke facilities support the research of strategic appointments in materials and biomedical research (Stranks, Kaminski-Schierle, Torrente, Fruk, Fairen-Jimenez, Ahnert), including clean room, class 2 and 3 bio-laboratories, and central computing infrastructure. CEB has also benefitted from closer engagement with researchers in other departments on the West Cambridge site.
2. *Translation of fundamental research into practice.* CEB has demonstrated its capacity to take knowledge across discipline boundaries. Exemplars include: development of optical imaging technologies to research viral vaccines and neurodegenerative disease; MRI technologies used to investigate reaction mechanisms in industrial plant (e.g. of catalytic pathway mechanism and performance); designing materials for applications from biosensors (e.g. engineered silk proteins) to energy (e.g. carbon capture), prosthetics (e.g. heart valves) and advanced materials (e.g. metallic glasses for aerospace).
3. *The Department will continue to develop 'off-shore' collaboration, increasing its capacity to promote sustainability worldwide*. CEB has continued to participate in, and provide directorship for, the development of the *Cambridge Centre for Advanced Research and Education in Singapore* (CARES) (§4.2). It promotes international collaboration with developing countries via its *EPSRC Centre for Doctoral Training in Sensor Technologies for a Healthy and Sustainable Future* (see §1.4) and the *Centre for Global Equality* (with CEB as a hub).

CUED

The following objectives, listed in REF2014, have been achieved:

1. *Secure donations and grants, use strategic funds and use other discretionary sources of income to invest in academic posts and research infrastructure to maintain and extend core disciplinary strengths in line with division aims and activities.* Two new professorships (Nanjing, Dr John C. Taylor Professor of Innovation), three new named lectureships (Acton, Granta (2)) and three new named research fellowships (Dowling (2), Ashby) have been created through philanthropic gifts and the sale of spin-off companies. Two new lectureships have been supported through industrial philanthropic gifts (Machine Learning and Computer Vision, Toyota). Strategic funds have been used to create 13 new lectureship posts over the assessment period.
2. *As research income continues to grow, maintain the share from industry at one-third, secured by building long-term strategic relationships.* Research income has increased by 18.4% since 2013/14, with the share from industry being at approximately 22%. Long-term funding relationships have been strengthened (including Dyson, Mitsubishi Heavy Industries, Rolls-Royce plc), and new relationships developed (including Boeing, Huawei, Toyota). Industry funding is below 1/3 due to growth in Government (non-Research Council) and charity research funding.
3. *Increase numbers of high-quality research students by winning new EPSRC CDTs, securing more industrial funding and attracting more philanthropic donations.* The number of research

students has climbed from 858 in 2014/15 to 987 in 2019/20, and CUED is involved with 8 new CDTs.

4. *Increase the numbers of high-quality postdoctoral researchers by making an increasing provision for them in grant applications, so that they can provide gearing for academics and build research capacity.* The number of postdoctoral scholars increased from 270 (216M, 54F) in 2013/2014 to 297 (236M, 61F) in 2019/2020.
5. *Improve the recruitment, induction, transferable skills training and career development for research students and postdoctoral researchers.* Transferable skills training is provided to research students at both divisional (domain-specific) and Department (library, language and communication) levels. Postdoctoral researchers are supported in career development by an expanded UCAM Office for Postdoctoral Affairs.
6. *Progress from a bronze award to gold under the Athena SWAN programme and achieve measurable improvements in the numbers of women applying for posts, securing appointments and winning promotions.* The Athena SWAN Committee has expanded its scope to address inclusivity, diversity and gender equality, and CUED has embedded EDI into its core governance structures during the assessment period. Athena SWAN Silver was achieved in 2017 and renewed in 2020, and work towards Gold continues.
7. *Invest to win significant funding for major projects under the T1 (Energy, Transport and Urban Infrastructure) theme, build stronger links across UCAM, including social sciences, and secure funding for new posts.* Funding was secured for the *Cambridge Centre for Smart Infrastructure and Construction* (CISC Phase 2 2016-2021, c. £3M), the Sustainable Road Freight 2 Project (2018-2023, EPSRC, £3.7M) and the UCAM *EnergyTransitions@Cambridge* IRC. The pan-University *Centre for Digital Built Britain* was launched in 2017 (Innovate UK, £5.4M to launch the Centre, £40.7M total), with CUED active in its governance.
8. *Shape the T2 (Uncertainty, Risk and Resilience) theme in collaboration with industrial and academic partners to build a solid intellectual foundation for the theme and win funding for landmark projects.* This theme was reshaped to *Complex, Resilient and Intelligent Systems.* Appointments were made to the Sir Kirby Laing Chair, random vibration (1 lectureship), and machine learning for robotic vision (2 lectureships) and a new Human-Machine Collaboration Observatory (supported by the UCAM Academic Seed Fund).
9. *Raise the profile of the T3 (Bioengineering) theme, forging ever stronger collaborations with the Schools of Biological Sciences and Clinical Medicine and Addenbrooke's Hospital with the aim of growing research capacity by 50% through new academic posts, additional research staff and more research studentships.* Additional lecturers were appointed in Bioengineering, Synthetic Biology, Healthcare Technologies, and Medical Therapeutics (joint with Physics); the *Centre for Engineering Better Care* was created (in collaboration with the School of Clinical Medicine, with seed funding from UCAM); the Institute for Neuroscience created (in collaboration with departments including Physiology, Development and Psychology, Mathematics and Physics); and the EPSRC IRC in *Targeted Delivery for Hard-to-Treat Cancers* was established.
10. *Bring our research and practice of knowledge creation and transfer closer together in the T4 (Inspiring research through industrial collaboration) theme, take a leading role in the UCAM, and embed the message that CUED excels in this field in its marketing.* This theme was reshaped as Manufacturing, Design and Materials, with numerous major successes, including the newly-endowed John C Taylor Professor of Innovation and the Boeing Supplier of the Year 2017 award. A Knowledge Transfer team was created over the assessment period, with 3 staff in 2020.

11. *To create over 2500m^2 of new space in CUED for multidisciplinary research, over 2000m^2 specifically for Division-B and improve the functionality and environmental performance of existing space.* Three major new research buildings have been developed: an extension for Division-B to house the *Cambridge Graphene Centre* (2600m^2, 2015, £12.9M, funded by UCAM); the James Dyson Building (2900m^2, 2016, £13.2M, funded by the James Dyson Foundation (£6M) and UCAM), a flagship building for energy efficiency which has incorporated structural sensing from CUED research providing research office and seminar space; and a new Civil Engineering building (4400m^2, 2019, £36M, funded by BEIS/EPSRC (£18M) and UCAM (£18M)). Redeveloped spaces include the Library and connected Dyson Centre for Engineering Design (1570m^2, 2016, £5.3M, funded by James Dyson Foundation (£2M) and CUED), supporting students in independent multidisciplinary investigation.

1.7 Forward Plans

Plans for UoA Overall

1. Ensure coordination across the UoA, as described in §1.2.
2. Continue work on gender equality and continue to broaden the scope to equality and diversity and inclusion. Implement initiatives from undergraduate teaching through to senior leadership, expand EDI training, and monitor Admissions, Teaching and Learning and Employment outcomes to inform EDI strategy. Integrate more research into undergraduate teaching to offer greater and deeper research exposure for undergraduates during their degrees.
3. Engage with UCAM's Development Office to raise funds for endowed chairs, lectureships and research studentships, for the provision of competitive recruitment packages for international talent and to support the activities of early-stage researchers.
4. Support UCAM and Government plans to achieve energy transition and decarbonisation of the economy by focused, multidisciplinary research, taking into account both technological and social factors. There will be strong contributions to *Cambridge Zero*.

DMSM

Consistent with its themes in §1.1, DMSM will:

1. Will grow overall by 20% over the 5 years from the 2018 Strategic Research Review, widening and intensifying fund-raising for key priorities, e.g. research studentships. Such growth implies four new academic posts (two already created, §2.2).
2. Further strengthen the Department's profile in computational materials science, taking a national lead in the Materials Discovery theme and building on success of the CDT in *Computational Methods*. Develop critical-mass strategies for materials research for climate change and sustainability. Increase industrial collaboration in the context of the Maxwell Centre.
3. Take the lead in the development of metallurgy for the future, appointing an internationally-leading scholar to the Tata Chair. Continue academic staff renewal to contribute to key themes, making appointments at international level.
4. Enhance support for all staff through targeted professional training and development including EDI training and a boosted appraisal processes.

5. Actively engage in the digital transformation of teaching and outreach. Enhance teaching facilities and progress modern methods of teaching. Develop and expand the existing provision of publicly-available online resources in Materials Science.

CEB

CEB will:

1. Expand capability in the fields of sustainable technologies and processes, and capitalise on associated opportunities, e.g. to decarbonise the chemical industries. This will be achieved through new academic posts in the area and strategic deployment of collaborative research networks led from CEB, e.g. the *Sensors CDT*, *SynTech CDT* and *CARES C4T* (§4.2).
2. Deliver a bespoke programme in responsible research and innovation, and entrepreneurial leadership to all researchers and to promote technological discovery in an ethical, sustainable and balanced manner.
3. Formalise the incorporation and use of open technologies in research and to facilitate this through the provision of a new, state-of-the-art makerspace workshop, providing facilities for rapid prototyping, mechanical and electronic design. Provide research training in these technologies to all incoming researchers.
4. Increase training in modern research methods at the undergraduate level.

CUED

In addition to the area research plans, CUED will:

1. Expand its research activity in the fields of sustainability, health, robotics, and data/AI for engineering systems through the creation of new lectureships to ensure the necessary capacity to address major long-term research challenges. Where possible, appointments will form bridges between academic divisions to stimulate multi-disciplinarity.
2. Construct the new *National Centre for Propulsion and Power* and redevelop the Whittle Laboratory to support research at the forefront of zero-carbon air transport, and to create dedicated spaces to support (i) closer engagement with researchers in other disciplines and (ii) deep engagement with industrial users.
3. Enhance support for new academics in establishing their independent research activities through targeted professional support, expanded and tailored financial support for research equipment and expanded mentoring.
4. Develop new programmes and initiatives to build and support multi-disciplinary research interactions within CUED as it progressively moves divisions from the city centre to West Cambridge, and to build collaborations with other departments on that site (CEB, DMSM, Computer Science & Technology, Physics); and strengthen collaborations with Clinical Medicine.

2. People

2.1 Staffing Strategy and Staff Development

Overall UoA Approach

The UoA supports excellence at all levels of employment and ensures that UoA12 policies are fully consonant with those of UCAM. There is effective liaison between UCAM's central HR function and the three Departments via the HR Business functions of the Schools of Technology and Physical Sciences. Strategy is directed towards:

(i) Recruiting and retaining talent. The objectives are to ensure that recruitment is managed strategically, aligned to institutional succession plans and to effectively manage the introduction of UCAM's plan for Academic Career Progression, which governs promotion. For professional and technical staff, a priority is to ensure that effective career progression opportunities are provided and that excellence is recognised, rewarded and shared through implementation of UCAM reward and recognition schemes. Great care is taken to ensure that all staff involved in recruitment and selection conduct fair and robust processes. Increased emphasis over the assessment period has been placed on ensuring that senior leaders and managers are fully equipped to manage staff to facilitate the retention of the best talent. There is access is to a range of required and voluntary training from UCAM, for staff at all career stages, covering research, teaching, administration and leadership.

(ii) Equality, diversity and inclusivity. Priorities are to improve the gender balance of the workforce and to develop management skills to ensure staff wellbeing and optimal performance. To ensure best-practice, consistent HR is employed across all Departments, including managing *EDI* and *Unconscious Bias* training for all staff. Tackling reported bullying and similar workplace issues robustly is emphasised, including raising awareness of UCAM's initiatives e.g. *Breaking the Silence* and *Dignity@Work*. Differences by gender and ethnicity on applying for promotion are now monitored, and follow-up actions include widening mentoring schemes and appropriate alterations to appraisal.

(iii) Organisational development and design. Departments review and adapt their staff strategies to ensure that they have optimal organisational structures enabling them to meet their current and long-term objectives.

2.2 Academic Recruitment

Overall Approach

For each appointment, a search committee is formed and tasked with advertising the post widely and publicising posts through international networks. Diversity of the appointment panels is carefully considered, and new requirements were introduced in 2014 to encourage diverse applicant lists: this is monitored by the Schools and has been successful in widening the pool of applicants. Short-listing panels must have at least one female academic member; strong candidates from under-represented groups are actively sought by search committees; and family-friendly policies are included in the further particulars. Chairs of search committees must report to the HoD or Head of School on what steps were taken to encourage a diverse pool of applicants. Short-listed candidates are invited for an intensive visit of interviews, presentations and discussion with academics.

DMSM

Since REF 2014, DMSM has recruited to 10 academic positions. The Goldsmiths' Chair (**Chhowalla**) leads a new research direction in low-dimensional materials, and the Sir Alan Cottrell Chair (**Pickard**) leads our focus in computational materials science. Lecturers appointed are: **Robinson** (now Professor), strengthening DMSM's leading role in superconducting spintronics; **Ringe** (jointly with Earth Sciences), leading work in the structural and optical characterization of natural and man-made materials; **Hirst** (jointly with Physics) leading work on semiconductor materials, especially for high-power applications; **Jones**, leading on novel metallic systems, including multi-principal element alloys and structural-functional materials for use in aerospace; **Evans**, developing novel photovoltaic materials; and **Kar-Narayan** developing polymer-based nanomaterials for energy-harvesting and sensing. In 2019/20, the focus on other funding sources secured a permanent Teaching Fellow from the JEO Mayne Trust (relieving pressure on research-active staff) and the appointment of two Lecturers, **Monserrat Sanchez** (in Computational Materials Science funded from the Gianna Angelopoulos Programme) and **di Martino** through an RAEng Award (Appointments overall 50%M, 50%F). Two further lectureship appointments will be made in 2021. Since 2017, seven staff have retired (UCAM's Employee-Justified Retirement Age, EJRA, is 67). Of the 7 relevant posts, 4 have been filled proleptically to retain strength in certain areas (materials chemistry, structural materials) and the strategy for the remainder is focused on recruitment of established leaders, or those with demonstrated leadership potential, at the highest international level of quality, ability and creativity. Supported by SPS and UCAM, DMSM delivers substantial start-up packages to attract the best internationally at all appointment levels. As a result, appointees have rapidly established sustainable groups, e.g. through ERC *Starting/Consolidator Grants* totalling c. £7M to **Evans**, **Ringe**, **Moya**, **Kar-Narayan**. DMSM recognises the strategic importance of attracting Research Fellows to nurture the best talent and explore new areas. In attracting staff at all levels, world-class infrastructure is vital; recent investments in equipment and our state-of-the-art building (2013), maintain DMSM at the leading edge of facility provision.

CEB

Over the last decade, CEB has grown its established academic posts to increase capability in key underpinning areas of fundamental research in materials, sensors and diagnostics and reaction and process engineering. In line with the strategy outlined in REF 2014, recruitment has continued to focus on succession planning and balancing a strong mid/late-career profile in CEB, taking into account fundamental research and teaching needs. Since 2014, ten appointments have been made:

1. *Mid-career and senior staff:* **Owens** (F) and **Smart** (F)) have wide experience and outstanding research records. **Owens** harnesses the power of engineering to develop *in vitro* biological models and uses this understanding for diagnostic and therapeutic development, bringing new bioengineering capability. **Smart**'s research in bioprocess development sees her return to academia following a prominent position in industry. These appointments are in line with the EDI agenda to achieve higher female representation at senior levels.
2. *Early-career appointments and succession planning:* Further recruitment (4M, 4F) has been made to develop core research strands for the future. **Stranks** (M) works, *inter alia*, on solar photovoltaics for energy generation. **Fruk** (F) works on Chemical Tools for NanoMaterials Engineering, designing new materials with biomedicinal function. **Torrente** (F) studies sustainable reaction engineering and green catalysts. **Fairen-Jimenez**'s (M) research concerns MOFs. **Kaminski Schierle's** (F) research is on the molecular mechanisms of

diseases. **Hallmark**'s (M) research is on non-Newtonian liquids. **Ahnert** (M) conducts work on theoretical aspects of biotechnology. **Marek** (F), a fixed-term Lecturer, works on chemical-looping processes**.**

3. *Early-career incubator:* CEB's effort on this has made good progress. Of the 15 Fellows cited in REF2014, four have been appointed to lectureships in UCAM (three in CEB) and others have taken up senior appointments elsewhere. In supporting ECRs in their transition to permanent academic posts, **Torrente** (see above) was appointed to a Lectureship, while holding an EPSRC Early Career Fellowship, **Fairen-Jimenez,** who was appointed as a Royal Society URF, moved to a Lectureship in 2015. Both have been promoted to Readers during the assessment period. **Stranks** (appointed to a Lectureship in 2019) will hold his Royal Society URF alongside his Lectureship until 2022. CEB has hosted 6 fellowships (College, Royal Society, Leverhulme, Marie Curie and RAEng). These Fellows are fully integrated with the Department and mentored in teaching and research to build an international reputation *en route* to a permanent position.

CUED

The overall aim is managed growth through new appointments in identified strategic, interdisciplinary areas to enhance collaborations across academic divisions and with other departments. The demographic balance of CUED is good; the mean age of established academic staff is 49, with 16% under 40 and 13% over 60. The UCAM EJRA allows proleptic filling of posts and aids an appropriate balance of experience.

The research domain for new appointments is defined by the HoD in discussion with the Academic Committee, with consideration of the research strategy developed through a range of internal and external consultations as described in §1.2. Over the assessment period, greater weight was given to building focused capacity with synergistic appointments for research impact in a fast-moving environment, while responding to changes in funding towards larger programmes. Clusters of appointments provide the depth and breadth to build strong programmes, e.g. the appointment of two Lecturers in the Internet of Things (strengthening the *intelligent systems* area) and two Lecturers in sustainability (strengthening the *environment* area).

Over the assessment period, 38 (28M, 10F) Lecturers and 8 (7M, 1F) Professors were appointed, including:

1. **Girolami** (M): Sir Kirby Laing Professor of Civil Engineering (from Imperial College), supporting strategic directions in data for engineering systems, providing a management-level interface to UCAM's Digital Built Britain Centre and strengthening the *cities and infrastructure* and *intelligent systems* areas.
2. **Malliaras** (M): Prince Philip Professor of Technology (from École des Mines de St. Étienne) in bioelectronics, linking bioengineering, sensing and electrical engineering themes, and strengthening the *healthcare* area.
3. **Viggiani** (F): Professor of Infrastructure Geotechnics (from Università di Roma), strengthening the *cities and infrastructure* area.
4. **Minshall** (M): John C Taylor Professor of Innovation, with a focus on technology and process management and strengthening the *technology management and policy* area.
5. Appointments to lectureships included **Davies Wykes** (F) to the Liz Acton Lectureship in Engineering, noteworthy because the terms of the post include promotion of women's participation in Engineering.

2.3 Academic Probation and Career Progression

Overall Approach

The importance of staff development at *all* career stages is recognised: training and support that address the challenges at different career stages are provided.

Early Career/New Appointments. Appointments of academic and research staff, at levels below Readership, are subject to satisfactory completion of 3- or 5-year probation depending on the length of tenure: **UCAM Pathways in Higher Education Practice** offers induction, personalised orientation and professional development during this period. Newly-appointed staff are assigned a **mentor**, tasked to advise and inform on everyday aspects of the new role and to share skills, knowledge and experience. More experienced staff can draw on peer-mentoring. Gender is carefully considered in conjunction with the staff member being mentored as there is evidence that this affects the success of mentoring. The scheme (most recently amended in 2019) is actively monitored, and is designed to be supportive and driven by the strategy of maintaining the highest international standards in research and teaching. Distinction in research, leadership and management and teaching is critical, and there is an expectation of internal and external contribution to the discipline. Teaching loads are carefully managed for probationers to assist them in developing their research profile. Each Department has its procedures for the assessment of, and support for, probationers. e.g. in CUED, cases are reviewed annually by an Academic Probation Committee (chaired by the HoD), with external references sought after 2 years in post, and again after 4 years in post. Subsequent support and training are provided to address any issues identified during the probation process. The DHoDs (Research) also support ECRs in navigating funding opportunities, and provide support in preparing research proposals and in building a research portfolio that balances collaborative work and the development of independence. A wide range of training courses is offered for ECRs. Support for UKRI Fellowship applications at Department and School level is coordinated across the UoA, providing assistance during writing, mentoring for appointed fellows, full integration into host Departments, and a staged career progression plan.

Mid-career The Departments recognise that mid-career staff face challenges around managing larger grants, leading larger groups, increased administrative load, and increased professional and personal time pressures. Staff at this stage are offered training on topics including project management, financial management, mentoring and leading teams. Staff are supported by Research Group Heads and/or the DHoDs Research and Teaching in building skills and working toward senior promotions.

Established staff taking on senior leadership roles follow UCAM *Senior Leadership Programmes* – intensive programmes for current and future leaders in the UoA and the wider UCAM.

Career Progression

Promotions to personal Readerships and Professorships require evidence of international research recognition and leadership, and a strong record in teaching and contribution to the department, UCAM and the field. The Senior Academic Promotions process is highly formalised, UCAM-wide and run annually, with final decisions made by a committee chaired by the Vice-Chancellor. HoDs (and Division heads in CUED) support academics in building their activities and profile in preparation for a promotion application, and suggest to academic staff whom they judge ready, that they consider a promotion application. This is critical for supporting diversity in senior academic promotions. Support for promotion applications is also available through the UCAM

Senior Academic Promotions CV Mentoring Scheme, designed particularly to encourage female academics to apply.

Since Jan 2014, **DMSM** has achieved 5 promotions to Reader (2F, 3M) and 7 to Professor (4F, 3M). In **CEB**, there was 1 (M) promotion to Senior Lecturer, 6 (3F, 3M) promotions to Reader and 6 (2F, 4M) promotions to Professor. In **CUED**, over the assessment period, there were 26 (1F, 25M) promotions to Senior Lecturer, 31 (6F, 25M) promotions to Reader and 23 (3F, 20M) promotions to Professor.

Academic staff are entitled to **fully paid sabbatical leave** to refresh their research (every seventh term), a stimulant of long-term career success. Departments also have formal **appraisal systems** for academics, and staff are strongly encouraged to identify training needs to be met by **Personal & Professional Development** courses.

2.4 Researcher Development

Overall Approach

UCAM's commitment to continued improvement is formalised in its *Code of Practice for Research Development, Code of Practice for the Employment of Contract Research Staff* and the *Concordat to Support the Career Development of Researchers.* Each Department has implemented the provisions of these codes and several further initiatives to support engagement with researchers and their professional development. All PDRAs have a supervisor (providing day-to-day research and professional guidance) and access to mentoring, e.g. provided in CUED by their own advisor (a senior member of academic staff not directly involved in the research), or in DMSM by a volunteer panel (Academic Staff, Research Fellows and experienced PDRAs). PDRAs receive an arrival induction that includes an introduction to the available support and training. The UCAM Accommodation Service offers support with housing, and UCAM recently opened the first £350M phase of the NW Cambridge development, including high-quality, sustainable housing for >700 staff. UCAM's **Head of the Postdoc Academy** coordinates and develops strategy for the entire PDRA community and acts as an advocate for PDRAs in UCAM's governance. Each Department has a Postdoc Committee to represent its PDRAs. Postdoc Committees report to Research Committees and directly to the HoD (CEB) or to the departmental Staff Committees (CUED and DMSM). The **Postdoc Academy** provides programmes for PDRAs in career and professional development, entrepreneurship, research translation, teaching and a careers service. PDRAs are also supported by UCAM **Researcher Development**. Subject to funding, promotion from PDRA to SRA is possible and cases are reviewed by the HoD, with approval required from the relevant Faculty Board. Promotion to PRA and Director of Research follows a process modelled on the Senior Academic Promotion Scheme. PRAs and Directors of Research are afforded PI status and can apply independently for grants and supervise graduate students. Outstanding PDRA work is also recognised through discretionary salary increments.

In **DMSM** the annual *Armourers & Brasiers' Company Fellowship* (£2,500) rewards outstanding PDRA performance. PDRAs are aided to submit strong applications for competitive research fellowships. Since Jan 2014, some 24 successful applications include: Royal Society URFs (×3); other Royal Society (Newton International, Industrial) (×6); Leverhulme Early Career; 1851 Research Fellowship; EU (Marie Curie) (×6); Overseas (Rubicon, DFG) (×2); Commonwealth Fellowship; UCAM Fellowships (Herchel Smith); Cambridge College Junior Research Fellows (×3).

In **CEB,** independence of researchers is actively promoted through a yearly appraisal process, and PDRAs who show leadership potential are encouraged by the Research Committee to seek

promotion to SRA status. Nine SRA appointments (6M, 3F) were made during the assessment period. Researchers are supported by senior mentors in the writing of competitive fellowship applications. During the period, CEB hosted Royal Society URFs (×2), EPSRC Advanced Fellows (1), Wellcome Trust Career Development Fellow (1), Leverhulme Trust (1), Shuttleworth Fellow (1).

CUED has created three new endowed research fellowships (Ashby and Dowling (2)) from philanthropic gifts for ECRs. Early-career researchers applying for competitive research fellowships receive guidance and support from academic and professional staff in developing fellowship proposals. Over the assessment period, successful applications for independent fellowships for ECRs to hold at CUED have included Blavatnik Fellowships, Cambridge College Junior Research Fellowships (×7), RAEng Enterprise Fellowships (×2) and Marie Curie Fellowships (×19), among many others. Holders of independent, early-career fellowships are assigned a senior academic as a mentor. An initiative in 2019, developed collaboratively by the Postdoc Committee and the Diversity Committee, is a peer-mentoring scheme where newly appointed ECRs are assigned a more experienced ECR as a peer-mentor.

2.5 Researcher Appointments to Other Institutions

Most Research Fellows and PDRAs progress to successful careers elsewhere. Developing them is an important national and international responsibility for UCAM and this UoA.

DMSM has a long record of members securing permanent academic posts. Since January 2014, at least 40 members of the Department have left to take up tenured/tenure-track academic posts, including at Beijing Institute of Technology, Birmingham (×2), Boğaziçi, Cambridge, Chengdu, Chinese Academy of Sciences, CNRS Strasbourg, Colorado, DGIST, ETH Zurich, Fraunhofer Institute, Imperial College (×4), Indian Association for the Cultivation of Science, Instituto de Ciencia de Materiales de Sevilla, Istanbul, KICET, KTH Stockholm, Kyung Hee, Leeds, Leicester, Lille, Malaysia, Manchester (×2), Monpellier, Nagoya, Nanjing, Northeastern University, Ohio, Peshawar, Sheffield, Technion, UNIST (Korea), UNSW, Yeungnam.

Several PDRAs from **CEB** have moved directly into tenured positions, including at Exeter University, Imperial College, Shanghai Jiaotong University, Vermont, Wageningen University, and UCL.

Many PDRAs and research students from **CUED** secured tenured or tenure-track academic posts at a range of institutions over the assessment period. Destinations include: Alberta, Bath, Birmingham, Brunel, Cambridge, Chinese Academy of Sciences, Chinese University of Hong Kong, Coventry, Dundee, Edinburgh Napier, Eindhoven University of Technology, Exeter, Georgia Tech, Glasgow, Groningen, Imperial College, Liverpool, Loughborough, Lund, Michigan State, Nagoya, National University of Singapore, Nottingham, Oxford, Sheffield, Southampton, Toronto, Tsinghua, UCL, and Warwick.

2.6 Research Students

Overall Approach

Recruitment of postgraduate students follows UCAM procedures, setting high academic criteria. Most applicants have a Master's degree in a relevant subject. Postgraduate students are admitted mostly to a PhD (3–4 years depending on the programme and funding) and some to a 1-year MPhil by Research. There is an open application process, with targeted recruitment also adopted. A large number of postgraduate students apply on the basis of the global profile and reputation of

the Departments. All shortlisted applicants are interviewed by at least two academics and candidates are ranked using consistent criteria for consideration for funding. Following UCAM's Code of Practice, each research student is assigned a **supervisor** to advise on the planning and execution of their research and to provide feedback. Support is offered by an **advisor** (member of staff in a cognate research area), also in the student's College (by a tutor, etc.) and by the Graduate Union. Financial support is provided by highly competitive awards from UKRI, EU, Cambridge Trusts and other UCAM, industry or home-country awards. The Board of Graduate Studies provides a database of funding opportunities. The **International Student Team** provides specialist advice. Overseas students must meet UCAM's stringent language requirements for admission. The Language Centre offers workshops and self-study courses, and Departments encourage attendance where improvement is needed. Training and support are coordinated by each Department's *Graduate Education Committee.*

Brexit presents an obvious risk to the recruitment of the best graduate students, mitigated through increased funding efforts for graduate students to offset any extra fee costs.

Training and Support

Across the Departments, postgraduate students can access libraries, workshops, experimental facilities, computing and the wide range of opportunities for developing technical skills. Year-1 induction includes a range of techniques lectures (~20 hrs) and two compulsory assessed masters-level courses. At the end of year 1, registration depends on submission of a first-year report and satisfactory performance in a *viva voce* examination in which questions may be asked on general background and courses taken and on the research itself. Benefits flow from being in the competitive, stimulating, supportive environment of high-achieving students and other researchers. Students are encouraged to attend research colloquia in their own Department, and beyond, to widen their perspectives, and they are encouraged to develop their skills further by demonstrating laboratory classes, supervising undergraduate research projects and teaching small groups ('supervisions', for which specialist training is given). The Departments prioritise postgraduate students attending, especially, international meetings, with support from Departments, Colleges, etc. being available.

Each Department participates in UCAM's Researcher Development Programme (RDP), with its comprehensive rolling provision of transferable skills training for all graduate students and researchers, including research, writing, presentation skills and team-building exercises. Research students must compile a record of completed training modules for consideration during their progress review after the first year of their PhD programme. Opportunities, including on-line courses, (e.g. from the Computing Service, Careers Service & Language Centre) are publicised to all students. As part of the RDP, students in **CUED** and **CEB** also organise annual Divisional, or Departmental, Research Conferences, respectively.

In all Departments, pastoral support is extensive. Students are encouraged to speak with their supervisor or advisor in case of difficulties. Where a student is uncomfortable discussing an issue with the supervisor or advisor, they can contact the DHoD Graduate Studies or a Graduate Student Mentor (a senior academic staff member, one of each gender). Students are also supported by their college Graduate Tutor.

Entrepreneurship

Entrepreneurship is fostered through UCAM's Entrepreneurship Centre which offers training and direct support for ECRs developing spin-out companies. Departments engage with the UCAM

Technology & Enterprise Club, a student organisation that hosts talks, workshops, mentoring and networking sessions to develop business insights. In CUED, students can also seek support from four Enterprise Champions.

DMSM

Recruitment and Admission

Each year, 30–40 postgraduate students are admitted, mostly to a PhD. The quality of DMSM's UK-educated intake is illustrated by the number of award winners including winners of the 2015 Royal Charter Prize and the 2018 R H Craven Award. On the census date, the student population was 52% UK, 21% EU, 9% China, 2% India and 12% other overseas. The exceptional quality of DMSM students and the value added by UCAM is shown by the many awards they receive (see below).

Doctoral Training Programmes

Apart from UCAM studentships, EPSRC DTG studentships and industry-funded studentships (e.g. iCASE), DMSM has participated, or still participates, in four 4-year programmes: 1) DTP in *Structural Metallic Systems for Gas Turbine Applications* (training integrated across Cambridge, Birmingham & Swansea); 2) EPSRC CDT in *Computational Methods for Materials Science*; 3) EPSRC CDT in *Nanoscience and Nanotechnology* (with specialist nanoscience and technology courses and courses in *science communication*, *business and research, management of technology and innovation*); 4) EPSRC CDT in *Graphene Technology*.

Student Awards

In the assessment period, DMSM postgraduate students, and those who have progressed to PDRAs/RFs, have won several prizes including 6 Cambridge Society for the Application of Research (CSAR) awards, College senior scholarships, best poster awards, best paper awards, *etc.* IOM3 granted Megan McGregor the accolade of one of the '15 under 30' to watch for the future. Robert Hoye was given a similar mention, and featured in *Forbes 30 under 30*. Samer Kurdi was accepted to participate in the 69th Lindau Nobel Laureate Meeting.

Progress Monitoring

After 9 months, PhD students must: submit a dissertation, successfully complete approved taught graduate courses and present to the student cohort in order to be formally registered for a PhD. The oral examination is by two staff members and covers the thesis, its general field and the content of the courses attended. Supervisors report on-line each term on progress. Reports, available to the student, are monitored by DMSM, Degree Committee, College, and Board of Graduate Studies, who recommend action in case of concern.

CEB

Recruitment and Admission

Applications for postgraduate research courses rose from 296 in 2013/14 to 553 in 2018/19. Entry is highly competitive and competition for places has increased, with 77 students admitted in 2013/14 and 107 in 2018/19.

CEB recruits doctoral students from diverse backgrounds, both in terms of first degree and nationality. Around 23% have an MEng in Chemical Engineering, 24% enter with a BSc in Chemical Engineering, with the remaining 51% holding degrees in Engineering, Chemistry, Physics, Biology, Biotechnology and Biochemistry. Recruitment is from across the world, typically 25% UK, 24% EU, 17% Americas, 3% Africa, 31% Asia and other overseas. Annual admission numbers are ~40, with a gradual increase. About 25% receive direct industrial or CASE awards, 21% are Research Council funded, 20% funded from UCAM trusts, 23% privately funded.

Doctoral Training Programmes

Alongside UCAM studentships, EPSRC DTG studentships and industry-funded studentships (e.g. iCASE), CEB participates in five 5-year programmes: the EPSRC *Sensors* CDT led by CEB, the EPSRC CDT in *Synthesis Technology*, the EPSRC CDT in *Nanoscience and Nanotechnology*, the EPSRC CDT in *Graphene Technology* and the EPSRC CDT in *Photonics Systems*. It also participates in the BBSRC Doctoral Training Programme.

Student Awards

Research students have won awards for their work, including L'Oréal Women in Science Award (L'Oréal Foundation), Biobeat 2018 winner, Vice Chancellor's award, Leete Premium Award, Munro Studentship and Barnes Prize, Robosoft manipulation competition and IROS 2016 Entrepreneurship award, Nigeria Scholarship award, Armstrong and Oppenheimer Award, Chinese Scholarship Council, Cambridge Trust Awards (×4), and have presented their work at >100 international meetings, where they have regularly gained awards for best poster and best presentation.

Progress Monitoring

This is the same as for DMSM, above.

CUED

Recruitment and Admission

Entry to postgraduate research programmes is highly competitive, with applications rising from 1388 in 2013/14 to 2129 in 2018/19. In 2013/14 336 students were admitted, and 299 were admitted in 2018/19, the small reduction being partly due to a shift to 4-year CDTs and in part a change in the balance of large research projects towards postdoctoral posts and fewer PhDs. CUED maintains a strong web presence to publicise the available graduate programmes, seeing applicants from 131 different countries in 2018/19. Typical admissions are 28% UK, 27% EU, 17% China, 10% N America and 18% other overseas.

Graduate open days are run on-site and funded studentships are advertised on jobs.ac.uk.

Doctoral Training Programmes

Over the assessment period, CUED has hosted 6 EPSRC Centres for Doctoral Training:

1. *Future Infrastructure and Built Environment* (FIBE), 2014-2022

2. *Gas Turbine Aerodynamics* (with Loughborough and Oxford), 2014-2022
3. *Graphene Technology*, 2014-2022
4. *Ultra Precision Engineering* (with Cranfield University), 2014-2022
5. *Future Infrastructure and Built Environment: Resilience in a Changing World* (FIBE2), 2019-2027
6. *Future Propulsion and Power* (with Loughborough and Oxford), 2019-2027

and has been a partner in a further 8 EPSRC CDTs:

1. *Integrated Photonic and Electronic Systems* (led by UCL), 2014-2022
2. *Nanoscience and Nanotechnology* (led by UCAM Physics), 2014-2022
3. *Sensor Technologies and Application* (led by CEB), 2014-2022
4. *Aerosol Science* (led by University of Bristol), 2019-2027
5. *Agri-Food Robotics* (led by University of Lincoln), 2019-2027
6. *Connected Electronic and Photonic Systems* (led by UCL), 2019-2027
7. *Integrated Functional Nano: Discovery & Design to Translation and Innovation* (led by UCAM Physics), 2019-2027
8. *Nuclear Energy Futures* (led by Imperial College), 2019-2027

and is a partner in the UKRI CDT *Application of Artificial Intelligence to the Study of Environmental Risks*.

Student Awards

CUED research students have received research awards that include: Amelia Earhart Award (Zonta Foundation), CASR Awards, DuPuy Prize, EPSRC Doctoral Prize, ERCOFTAC Da Vinci prize, IET Achievement Award, IET Hudswell International Research Scholarship, IMechE Whitworth Visionary Award, IoP Best Combustion Dissertation Award, Merck Displaying the Future Award, Royal Academy of Engineering *Enterprise Fellowship*, RSC *Chemistry Means Business* award and the Scopus *Young Researcher UK Award*.

Progress Monitoring

A formal review of progress is conducted by the Head of Division and the adviser, who consider performance in taught courses, attendance at professional development courses, a report from the supervisor and the written research report. The high level of support combined with the high performance expectations ensure a strong platform for the subsequent stage in the PhD programme, and a well-managed exit for the small number for whom it is not in their best interests to continue. Students who progress from the first year present an updated research plan at the end of the second year in a formal meeting with the supervisor and adviser. The first-year progress examination and the second-year review provide a strong platform from which to work towards submission of a high-quality thesis within four years. Students are encouraged to engage in teaching to develop their professional profile, with the time commitment carefully managed as part of the progress monitoring.

2.7 Equality, Diversity and Inclusion

The Departments embed EDI into all aspects of their operation and strategy. CUED holds Athena SWAN Silver (renewed in 2020) and CEB and holds the Bronze award with submission for renewal made in 2020. University initiatives are fully supported. For example, UCAM's *Women in Science, Engineering & Technology Initiative* from UG to professor includes: a CV-mentoring scheme; an annual lecture from women scientists working in policy, industry and academia; career-development seminars for early career, postdoctoral and PhD-level women scientists; a Senior Gender Equality Network; maternity/paternity/adoption leave provisions more generous than required by law; and a Returning Carers' Scheme to catalyse the return to research. All staff are encouraged to take *EDI* and *Unconscious Bias* training, and this is rigidly enforced for those with management or recruitment responsibilities. The *Dignity at Work* policy is explained to new staff, supported by workshops. Departments have *Wellbeing Ambassadors*, who promote physical and mental well-being initiatives and direct students and staff to UCAM's support services (e.g. *Occupational Health Service, Counselling Service*). Staff and students with a disability are assessed by UCAM's *Disability Resource Centre*, which liaises with departments about measures to accommodate requirements. UCAM has two workplace nurseries and provides a holiday playscheme. Each Department supports UCAM's *Breaking the Silence* campaign on harassment by means of seminars and focus groups.

DMSM: since 2019, the EDI Committee's primary mission has been to develop a wider strategic vision. There are distinct, externally moderated focus groups for students and staff at all levels. Gender and race statistics are being analysed, including recruitment processes. In the academic year 2019-20, women in key cohorts were: UGs 37%, PGRs 31%, PDRAs 25%, and Research Fellows, independent researchers & academic staff 33% (of which, Senior Lecturers and below 25%; Readers and above, 40%). At Professor grade, DMSM currently has 33% female representation. BAME representations in staff cohorts in 2020 were PDRAs 39%, academic staff 24%, and technical and administrative staff 10%. Monitoring of other protected characteristics will be addressed where possible.

CEB: the Diversity@CEB initiative was launched in 2017 to champion the range of staff backgrounds. EDI matters covering the full range of issues are the responsibility of the Athena SWAN Committee, chaired by the HoD, supported by the Department HR advisor, and reporting directly to CEB's Staff Committee. Research student and staff surveys were conducted in December 2017, with participation rates over 85%. As a result, changes in the Consultation and Decision-Making processes have been implemented to improve communication flow and achieve a better integration of all members of the Department. From 2013 to 2019, 1762 (1135M, 627F) graduate applications were received. Subsequently, admissions were made: in 2013–14, 51 (32M, 19F) Master's students and 27 (16M, 11F) PhD students; in 2018–19, 68 (46M, 22F) Master's students and 43 (26M, 17F) PhD students.

In **CUED**, implementation of equality and diversity plans, and their monitoring, is overseen by the Diversity Committee, which covers all aspects of EDI. Membership is diverse and includes academic, research and professional staff at all career stages and senior leadership. A member of the committee is the dedicated diversity representative on the Engineering Faculty Board (a statutory Council with responsibilities for education and research). Initiatives on equality and diversity are promoted online. The fraction of female research staff in 2019 was 22%, Lecturers 23% and Professors 11%. In 2019, 20% of applicants for academic posts identified as female, and for these posts 44% of the appointed staff identified as female. Ethnicity data are held for 90% of academic staff (staff can choose to not disclose), with 15% of academic staff coming from an ethnic minority in 2015, rising to 18% in 2019. In 2015 40% of research staff were from an ethnic

minority, and this was 44% in 2019. CUED has a detailed action plan, part of its Athena SWAN submission in 2020, addressing EDI.

2.8 EDI in Preparing the UoA12 REF Submission

All members involved in the REF process (including departmental sub-committees and the main UoA12 REF Committee) have undertaken the training contained in the UCAM *Code of Practice* concerning *EDI* and *Unconscious Bias*. EDI was a standing item at UoA12 REF Committee meetings and all decisions were rigorously examined in the light of EDI and Unconscious Bias. The *Code of Practice* also sets out the measures taken to ensure that any bias related to EDI in output selection has been eliminated as far as possible: UoA12 followed the guidance exactly.

2.9 Returning from Periods of Leave and Caring Responsibilities

Departments are fully in line with UCAM Policies, described in the Institutional Statement.

2.10 Conclusion

HR practice concerning academic staff, researchers and research fellows and students is based on common policies and approaches, dictated by UCAM policy. There is local variation, e.g. in the exact details of training of research students and the availability of departmental-specific awards, but these allow adaptation to local needs. All Departments expect excellence, but with policies in place to ensure equality of treatment, mentoring, fairness, help and support. The UoA is not complacent: EDI, particularly regarding BME recruitment and progression, remains a critical focus.

3. Income, infrastructure and facilities

3.1 Strategies for Generating and Growing Research Income

For **DMSM**, annual research expenditure is £10.27M (2019-20) (latest year with full data). The 348 grants activated over the assessment period total £76M (excluding EPSRC studentships but including industrial student support). For these, the sources are: EC (15.2% of total value); EPSRC (53.5%); industry (11.3%), from 32 companies (largest £833k for SKF UTC), charities (Royal Society, Leverhulme Trust, etc.) (16.2%); UK Government (0.5%), overseas (3.3%). Within the EC, £7,659k is from five ERC grants. Charity support in the same period includes £180k from the Isaac Newton Trust, a source unique to UCAM. DMSM Trust Funds, yielding £344k p.a., provide further research support. Since Jan 2014, there has been significant philanthropic support, giving a total of c. £675k: including a pledge from the Goldsmiths' Livery Company (£385k) for studentships, and £92.5k from the Armourers and Brasiers' Company. DMSM has a full-time Research & Business Development Manager to promote its important links with industry. Post-Brexit, a focus is to build on the current momentum in philanthropic fundraising.

Total research income for **CEB** for the rolling five-year period from 2012/13, was £43M with an anticipated average for the assessment period of £40–45M. The number of grants has increased by 50% in 2016-17 compared with 2012-13. Collaboration with European industry and academics was strong through projects (such as TRANSCEND, BiognostiX, Ocmol, Schizdx, Recoba, Spire-4-mea, Nanodome, NirZA, PEMS4Nano) as well as a Marie Curie ITN (SUPUVIR), together with two ERC grants (IMBIBE and Rational Design). CEB currently has ~40 industrial collaborations providing an annual income of c. £3.5M, many enabled through CEB's staged engagement model, offering different levels of collaboration, ranging from short-term pilot studies (e.g. research projects for Master's students) or consultancy, to fully funded research programmes. The *Sensor* CDT, renewed by EPSRC in 2019, has raised £3.2M in industrial partnership funding with this approach.

CUED pursues a balanced research income strategy of UKRI, Government, industry, charity and philanthropic funding. The total value of activated external research grants over the assessment period was £325M. Of the 939 grants activated, the sources were: EC (17.3% of total value), EPSRC (41.5%), industry (22.4%), charities (4.8%), UK Government (8.6%). The HoD works with the SoT and the UCAM Development and Alumni Relations Office to secure philanthropic gifts in support of research. During the assessment period, over £18M of philanthropic support has been received.

IfM Engage is a wholly owned subsidiary of UCAM for knowledge transfer and training. It returns profits to CUED (via Gift Aid) to support research and teaching, and in 2019 gifted £436k to CUED. Further Gift Aid of £3.1M was received in the REF period, reflecting profits from commercial enterprises spun out from CUED.

EU income was £8.9M in 2013/14 and increased to £11.1M in 2017/18; hence Brexit presents an income risk. Charity income increased from £0.6M in 2013/14 to £3.6M in 2019/20 driven by increased biomedical/engineering research, and this income generally has lower rates of cost recovery. To mitigate the Brexit risk, CUED aims to expand its funding portfolio from UKRI and industry, with new dedicated professional support for the preparation of multi-partner and multi-disciplinary proposals.

Overall Conclusion

Brexit represents a considerable challenge for sustaining EU collaborations and income, but Departments are taking mitigating action, largely with renewed action on industrial funding and philanthropic funding for research posts. Flexibility of research offerings (from small projects and consultancy to major ones) is critical.

3.2 Organisational Infrastructure Supporting Research and Impact

Each Department operates a Research and Finance Office providing dedicated grant support for research-funding applications, sponsor-relationship development, research contracts, compliance, impact and translation. Knowledge Transfer (KT) Teams lead the support for academics preparing research proposals from an early stage, and extensive guidance is provided on departmental intranets. The KT Teams check proposals for ethical and integrity issues that may require additional scrutiny and provide expertise on impact planning and advice on the structuring of research collaborations with industry to maximise the likelihood of research outputs being adopted.

For **each Department**, the Research Office publicises calls for proposals via e-newsletters or emails and the DHoD (Research) identifies matches between funding calls and academic staff. Early-career academics receive support for the preparation of proposals, and senior academics with relevant experience are drawn in to provide guidance and feedback. Mock interviews are held to support fellowship applicants. Workshops are held for ECRs on developing successful fellowship applications, and this includes peer support from previously successful applicants and senior academics. In **CUED**, the Director of Strategy and Operations and the KT Team provide specialist support for the exploitation and translation of successful research and work closely with CE. In **DMSM** and **CEB**, CE runs monthly clinics where researchers can test the transfer potential of developed technologies.

3.3 Operational and Scholarly Infrastructure Supporting Research and Impact

In **DMSM** 48 (45% F) professional support staff manage facilities and infrastructure within a dedicated building (§3.5) containing high-specification research laboratories and teaching facilities. The design of the building enables groups from within DMSM to mix easily and promotes the ethos of interdisciplinarity and collaboration. The HoD and DHoD (Research) are responsible for research strategy and policy. The Graduate Education Committee oversees graduate student education and researcher development. DMSM has an IT team of (1 full-time, 1 part-time) supporting research, teaching and administration, supported by IT-proficient staff embedded within research areas. The IT team advises on hardware and software purchases, cyber security, data protection and GDPR and is central to the reliable secure operation of DMSM's digital infrastructure. Academic direction of research computing support is discussed at the Computing Committee, which reviews strategic and operational research IT needs.

In **CEB** 46 technical and administrative support staff manage facilities and infrastructure. The operational structure was reviewed following the restructure of the Department in 2020. A new Technical Operations Manager (TOM) post was created to oversee major research infrastructure and research support staff. The DHoD (Research) and the Research Committee are responsible for developing the research profile and formulating CEB's research strategy and policy, also overseeing, as noted on page 3, research integrity, safety and ethics, open research, research engagement and, via the Graduate Education Committee, researcher development.

CUED employs 88 technicians, 29 IT support staff and 10 HR staff. A dedicated Engineering Library is located onsite, with 6 library staff. The Library specialises in research data management, open research, and scholarly practices and communication. The Library space was redeveloped in 2016 to better accommodate its revised mission as a centre supporting scholarly communication and data management. The Library supports a "Data Champion" hub of research staff, IT staff, and PhD students in CUED who promote research data management best-practice. The Department IT Team supports research, teaching and administration, with oversight from the Academic IT Committee. The IT Team advises on data security for research projects in terms of best practice and on compliance requirements.

Each Department engages with wider UCAM research computing services by membership of their respective School's IT Strategy Committee.

3.4 EDI in the Context of Funding and Access to Infrastructure

As noted in §2.7, each Department embeds EDI into all aspects of its operation and strategy. Research Committees review distribution of funding, special problems concerning accessibility to infrastructure for those with disabilities and take appropriate measures. During staff appraisal, the difficulties experienced in obtaining funding, support for applications or accessing appropriate equipment are discussed and corrective actions initiated.

3.5 Infrastructure, Facilities and Expertise in Relation to Impact

DMSM

UCAM investment in buildings and site infrastructure on the West Cambridge Science and Technology Campus provides a vibrant location for DMSM, close to CEB, Civil Engineering, Electrical Engineering, the Maxwell Centre, the Hauser Forum (housing Cambridge Enterprise and the Entrepreneurship Centre), the Institute for Manufacturing, Nanoscience and Physics. DMSM completed its move in 2014 to a £50M new building. The gross internal floor area of 10,600m^2 gave 31% extra lab space to accommodate DMSM's research to a globally competitive standard. The **Wolfson Electron Microscopy Suite** is on a separate 2 m-deep concrete slab, providing rooms with low-vibration ratings (NIST grade A); acoustic and electromagnetic interference are also at state-of-the-art low levels.

Spend on infrastructural items exceeding £10k in the assessment period was £5,756k (UCAM £125k, EPSRC £4,657k, EC £858k, overseas government/industry £67k, Innovate UK £29k, charity £20k). Major items included a carrier for the MOCVD system (£240k EPSRC), a Micro CT scanner (£225k EC), and an Aerosol Jet System (£133k EC). The Royce Institute awarded DMSM £2.3M to purchase a focused ion beam instrument (£534k), a sputter system (£285k), a TEM high-speed camera (£274k), a cryogen-free SQUID (£639k) and a wafer-scale AFM upgrade (£348k). Two EPSRC-funded (total ~£5M) (**strategic equipment**) electron microscopes were installed, allowing ultrafast SEM dedicated to undertaking novel cathodoluminescence studies and STEM enabling 'multi-dimensional' microscopy. These instruments are available to UCAM and external researchers.

CEB

CEB occupies a £60M purpose-built building (operational since 2016) on the West Cambridge Science and Technology Campus. The building houses the whole cycle of scientific investigation in chemical engineering and biotechnology under one roof and brings together a vibrant, creative community in which chemical engineers and biotechnologists achieve an unprecedented level of integration. This environment gives the facilities, resources, and inspiration to solve pressing challenges. Over the assessment period, ~100 items of equipment were purchased in CEB of value greater than £10k, totalling £5M, including materials and chemical analysis equipment, such as mass spectrometers, atomic force microscope, THz spectrometers, and NMR, microscopy, chromatography and HPLC instruments.

CUED

The CUED has >47,000m^2 of building space, with ~12,500m^2 of laboratory space, 2,500m^2 of lecture/seminar spaces, and 2,000m^2 of workshop space. Over the assessment period 9900m^2 of new building space for accommodating divisions and to house research facilities for new and expanding activities was developed. The new Civil Engineering Building (4400m^2, £36M) in West Cambridge was delivered in 2019. It houses the **National Research Facility for Infrastructure Sensing** and includes new structures research laboratories. The James Dyson Building (2900m^2, £13.1M), completed in 2016, provides space for researchers from across multiple divisions, supporting inter-disciplinary interactions and multidisciplinary research. The Electrical Engineering Annex (4400m^2, £12.9M) was completed in 2016 and houses the *Cambridge Graphene Centre*. Over 1220m^2 of other laboratory space was developed or refurbished, including the multi-disciplinary *Bio-inspired Robotic Laboratory* and *Human-machine Collaboration Observatory*.

Over the assessment period, over 400 research equipment items valued at more than £10k were purchased, with a total value over £28M. Major purchases include a Raith EBPG5200 Electron Beam Lithography system (£1.8M, 2018), quantum key distribution systems (£1.8M in 2016 and £1.2M in 2019), a Power Device Analyzer/Curve Tracer mainframe (£714K, 2017), a PHOIBOS 150 1D-DLD NAP Analyzer Package (£677K, 2017), and a high-resolution 3D x-ray tomography microscope system (£535K, 2017).

3.6 Specialist Research Infrastructure

DMSM supports diverse specialist research facilities, notably a comprehensive range of precision thin-film-growth systems (8 UHV sputter, 5 pulsed-laser deposition and 2 GaN MOCVD), processing systems for nanomaterials and nanotubes and extensive capabilities for structural and property characterisation. X-ray diffraction (XRD) and electron microscopy (EM), operated as Small Research Facilities (SRFs). These facilities, fully staffed with appropriate technician expertise, serve all DMSM's specialities, and, because of their quality and range (boosted by recent purchases of state-of-the-art instruments in each class, §3.4), they attract external users. The XRD facility has instruments ranging from standard powder diffractometers to high-resolution and small-angle systems. It has ~100 users each year, 15% from outside DMSM. WEMS has 6 scanning-electron/focused-ion-beam microscopes and 7 transmission electron microscopes. Each year, the EM Facility trains >100 (15% from outside DMSM) and has ~300 users (DMSM, 12 other UCAM departments and external users). DMSM researchers have access to a wide range of equipment (e.g. SQUIDs and specialised XRD) in other UCAM departments. The UCAM Library provides access to ~90,000 electronic journals and ~400 databases.

CEB has world-leading imaging facilities for the characterisation of materials, process and biological specimens. For example, the microscopy suite offers methods for optical super-resolution and functional imaging of processes ranging in scale from single molecules to living cells and over timescales from picoseconds to days. Instrumentation developed in CEB includes STED (stimulated emission depletion), SIM (structured illumination microscopy), LSM (light sheet microscopy) and FLIM (fluorescence lifetime imaging microscopy). The magnetic resonance research centre (MRRC) is a world-class facility with wide ranging expertise in the application of magnetic resonance techniques to academic and industrial research in the field of chemical, biochemical, and petroleum engineering. It houses eight medium-field and five low-field NMR/MRI spectrometers.

CUED operates 20 Research Facilities (RF) which can be accessed by users within and outside UCAM. In 2019/20 £142k was received from UCAM (outside CUED) for use of the RFs, and £129k from external users. Facilities include clean rooms, microscopy systems, laser systems, electron beam evaporation and computer infrastructure. Shared materials research facilities are operated on behalf of the Royce Institute. **CUED** established in 2019 the *National Research Facility for Infrastructure Sensing*, part of the national UKCRIC Network. The facility, which includes the new Civil Engineering building, was developed with a £18M grant from UKRI which was matched by a £18M UCAM contribution. £6M was invested in new research facilities, which can be accessed by external users.

3.7 Evidence of Sharing of Major Facilities

For **DMSM** and **CUED**, see §3.6. In **CEB** microscopy instrumentation, developed in CEB, is duplicated in the UCAM Advanced Imaging Centre, in UCAM's School of Biological Sciences and used by researchers from departments spanning Clinical Medicine to Technology. A satellite facility was opened at the UK Dementia Research Institute, located on the UCAM Biomedical campus and providing ready access to researchers at Addenbrooke's Hospital.

All Departments benefit from UCAM's £20M investment in the West Cambridge Data Centre. The Centre houses one of five national Tier 2 high-performance computing systems, supporting research across the UoA.

Overview for the UoA

The approach to income generation, infrastructure and facilities is framed by the strategic research objectives of the Departments, including the creation of internationally leading research outputs and the translation and impact of research for economic and social benefit. Excellent support is given for researchers at all levels to develop proposals and collaborations. With major equipment, a strategy of ready access for researchers, both from UCAM and outside, is important, backed-up by coherent charging models.

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

4.1 Research Collaboration and Engagement

UoA12 has a culture of collaboration outside UCAM and extending globally; UCAM's sabbatical policy facilitates outside links and the reputation of UCAM and UoA12 Departments attracts key visitors. Colleges facilitate visits through accommodation and by providing Visiting and Overseas Fellowships. External academic collaborations are supported by each Department's Research Office and the UCAM Strategic Partnerships Office.

DMSM

In the assessment period, DMSM has signed MoUs/agreements with institutions in Japan, Oman, Russia (×2) and Germany (×2). International collaborations are often supported by specific funding, e.g. funding since Jan 2014 includes 19 collaborative EC FP7 grants, and 90 grants from overseas/multinational companies. A random sample of 158 DMSM papers published within the assessment period (Jan–Sept 2019) showed extensive collaborations outside DMSM, 50 with another UK university and over 140 collaborations with overseas universities: Australia (×2), Canada, China (×31), France (×11), Germany (×15), India (×11), Ireland (×4), Italy (×3), Japan (×11), Malaysia, Netherlands (×4), Norway (×2), Oman (×4), Poland (×4), Portugal, Singapore (×4), South Korea (×6), Spain (×4), Switzerland (×12), Taiwan, USA (×15).

CEB

CEB academics have Visiting Professorships in Rotterdam, University of Paris-Descartes, Max Planck Institute for the Science of Light, University of Erlangen/Nuremberg, Nanyang Technological University and University of Zhejiang. Over the assessment period MoUs/research agreements were signed with Zheijang University, CARES Singapore; North Carolina State University, Singapore Polytechnic. Of the 108 papers submitted by CEB staff for inclusion as REF outputs, there were collaborations with researchers from 73 different universities (20 UK, 53 non-UK) in 20 different countries. CEB engaged in 19 collaborative FP7/H2020 projects over the assessment period.

CUED

In the assessment period, members of the Department have published outputs with collaborators from over 1500 other institutions and over 80 different countries, and over 1750 research visitors from more than 76 different countries have been hosted for periods of two weeks or more. CUED provides seed funding for new initiatives, e.g. the CUED/U. Michigan scheme started in 2018 offers grants for research collaborations. In 2018 the UCAM–Nanjing Centre of Technology and Innovation was created to foster new research collaborations, with CUED as the UCAM hub. CUED received £10M from the Nanjing Municipality to support the Centre and to endow the Nanjing Chair in CUED. Collaboration agreements/MoUs are in place between CUED and 17 universities.

4.2 Major Interdisciplinary Research Links

DMSM

The breadth of DMSM favours interdisciplinarity, even within DMSM, and promotes outside links (e.g. medical-materials collaboration with Orthopaedics Research at Addenbrooke's Hospital). DMSM also favours engagement with UCAM research centres bridging departments and disciplines. One example is *The Lennard-Jones Centre for Computational Materials* linking research across DMSM, CEB, CUED and Physics. The Maxwell Centre (introduced in §1.6), as well as being a remarkable forum for industry-academic links, encourages interdisciplinary, inter-departmental research with key stakeholders being Physics, Chemistry, CUED, CEB and DMSM. The Centre is also home to the Cambridge spoke of the national Royce Institute. DMSM plays a key role in providing instrumentation and research expertise to the Institute and in leading UCAM's core area of *Materials for Energy-Efficient ICT*. DMSM is engaged with the Faraday Institution and battery research undertaken in UCAM led by *Chemistry*. DMSM is also engaged with long-running European networks such as ESTEEM, linking 14 institutes and SMEs across Europe to develop novel electron microscopy techniques. It is a key player in the national ADOPPT programme for advanced digital design transforming pharmaceutical development.

DMSM is strongly involved with UCAM's *EnergyTransitions* IRC, *Cardiovascular* IRC and *Sensors* Strategic Research Network (SRN) (exploiting technologies developed across UCAM to encourage innovation through interdisciplinary collaborations). DMSM is also a key player in the *Cambridge Creative Circular Plastics Centre*, a UKRI-funded programme acting as a nucleus for a global network of partners and research projects.

CEB

Members are involved in ~25 main collaborative grants with other departments in UCAM, including the *Sensors* CDT. CEB is the lead PI in 10 of these grants, with CUED being the most frequent partner. CARES (http://www.cares.cam.ac.uk/) is funded by the National Research Foundation of Singapore and hosts research collaborations involving UCAM, Nanyang Technological University, the National University of Singapore and industrial partners. The CARES C4T programme was set up in 2013 to reduce the carbon footprint of Singapore. By the end of 2017, there were 120 researchers connected with CARES, producing more than 270 publications. C4T and CEB researchers also undertake research with UC Berkeley on the electroreduction of CO_2.

CEB is strongly involved (via 1 PI, 2 PDRAs and 6 PhD students) in the BP Institute (BPI), which links 5 parent departments for interdisciplinary research in fluid mechanics and surface science. Research in the BPI ranges from carbon sequestration to encapsulation of bioactive materials.

CEB participates in the *Global Challenges* SRI, the *Cambridge Academy of Therapeutic Sciences*, and leads UCAM's Sensors SRN, connecting more than 100 PIs.

CUED

Within UCAM, CUED participates in the cross-School *Cambridge Centre for Data-Driven Discovery*, *Cardiovascular Disease*, *Energy Transitions*, *Global Challenges*, and *Synthetic Biology* Strategic/Interdisciplinary Research Initiatives, in the completed SRIs in *Public Policy* and *Trustworthy Technologies* and in the *Sensors* Strategic Research Network. In 2019 the *Centre for Engineering Better Care* was created in collaboration with the School of Clinical Medicine, building on already strong connections. The *Cambridge Public Health IRC* and the *Centre for Engineering Better Care* are hosted by CUED, promoting interdisciplinary interaction. CUED fully engages in

the Maxwell Centre, particularly on projects related to energy transition and on *Energy-Efficient Materials for ICT*. Examples of interdisciplinary links through national bodies include the Royce Institute, the Faraday Institution, and the Alan Turing Institute. Two CUED members are Directors of the Alan Turing Institute and numerous staff hold fellowships.

4.3 Interaction with Users and Beneficiaries to Develop Impact

DMSM

Over the assessment period, DMSM has collaborated with c. 40 companies. DMSM's oldest (1994) link with industry, its Rolls-Royce UTC, focuses on next-generation materials for cleaner gas turbines. It has been successful in its research and in training world-class materials scientists and metallurgical engineers, as evidenced by its longevity. The UTC has attracted 10 DMSM academics (and 2 in other UCAM departments) to work in relevant areas and, in turn, benefits from their input. The SKF UTC (2009-2018) was inspired by the Rolls-Royce UTC and was a highly successful Centre employing 14 researchers including ADR and SRA positions. DMSM continues to explore possibilities with other companies. BP's *International Centre for Advanced Materials* (ICAM, 2012–) aims to advance fundamental understanding and the use of advanced materials across the oil and gas industry. Led by Manchester, ICAM has spokes in UCAM, Imperial College and the Univ. of Illinois at Urbana-Champaign. ICAM has funded DMSM's **Bhadeshia** to design steels resistant to hydrogen embrittlement. DMSM has also broadened its involvement in pharmaceutical research through hosting a cryo-microscope as part of a FEI/Thermo pharmaceutical consortium linking 5 pharmaceutical companies with academic and industrial partners.

CEB

Over the assessment period, CEB has interacted with >35 industrial companies. Exemplars are the Beacon project with AstraZeneca (7 Beacon-funded PDRAs, 11 PhDs) that links the global biologics research and development arm of AstraZeneca with CEB to produce breakthroughs in biopharmaceutical development. Research includes cell engineering, continuous processing, formulation, and analytical science, to support potential new therapies.

CEB hosts the *Cambridge Infinitus Research Centre*, CIRCE, (1 SRA, 6 PDRAs, 2 PHDs) with the mission to research the biological activity of natural compounds in the context of ageing diseases. The programme has been approved for another £4M funding cycle, starting in Sept. 2020.

Shell has a partnership between CEB's *Magnetic Resonance Research Centre* (MRRC) and company laboratories in Houston and Amsterdam. The work is based on the MRRC's expertise in adsorption, transport and reaction in porous media, and has been supported by a donation which has established a capability for MRI under process conditions.

Through the *Syntech* and *Sensors* CDTs, CEB co-ordinates research with more than 30 industrial partners, leading to more than 20 industry-funded research studentships over the assessment period.

CUED

Over 170 industrial partners have supported research during the assessment period, with 38% of industrial grants (54% by value) from companies outside the UK. CUED has a long-standing research partnership with Rolls-Royce plc, which includes the *University Gas Turbine Partnership*

(UGTP, in place since 2001). The UGTP funds two members of academic staff, 12 researchers, nine PhD students and four support staff. Two Impact Case Studies – compressor blade leading edges and s-ducts – have followed from this partnership. The collaboration with Rolls-Royce has expanded into new fields over the assessment period, with CUED breadth and multi-disciplinarity in research supporting broadening Rolls-Royce inter-disciplinary needs in new fields, including electric propulsion. An example is the EPSRC *ASiMoV Prosperity Partnership* with Rolls-Royce on advanced computing and simulation (£14.1M, 2018–2023), in which CUED is one of 5 university partners. CUED has a framework agreement with Mitsubishi Heavy Industries that supports two academic staff (since 2008), two senior College Research Fellows, and 10 research projects annually supporting 6 PDRAs and 5 research students. Much of the research is centred in the Whittle Laboratory, which works closely with Rolls-Royce, Mitsubishi and Siemens on turbomachinery; its future work will concentrate on decarbonising aviation and land-based power.

The *Laing O'Rourke Centre for Construction Engineering and Technology*, started 2010 and renewed in 2020 for a further 10 years, receives annual funding of £1M from Laing O'Rourke and supports three academic staff (1 Professor, 2 Lecturers). In 2019 the *Toyota-Cambridge Centre for Next Generation Artificial Intelligence* was formed with a £2.5M contribution from Toyota Europe. Two lectureships have been created with the support, and framework agreements developed for additional targeted research projects supported by Toyota. The *Huawei-Cambridge AI Centre* was created in 2019 with £5M over 5 years for a joint centre between CUED and the Department of Computer Science and Technology (CST). The Centre supports 5 PhD studentships per year between CUED and CST. Examples of other centres include: the *Centre for Advanced Photonics and Electronics*, a partnership between CUED and 5 companies and the EPSRC Centre for *Innovative Manufacturing in Large-Area Electronics*, with 9 academic and 64 industrial partners. Other major companies with strong research connections to CUED include Arm Ltd, Boeing, Dyson and Jaguar Land Rover. CUED has been successful in each round of the EPSRC Prosperity Partnership scheme for university/business consortia, with 5-year Prosperity partnerships with BT (2017), Rolls-Royce (2018, mentioned above) and Microsoft (2019).

The *Cambridge Centre for Smart Infrastructure and Construction* is funded by Innovate UK, EPSRC and industry to support the development and deployment of leading sensing and data analysis technologies through collaboration with partners. The *Cambridge Service Alliance*, founded 2010, involves CUED, IfM and leading engineering firms, e.g. BAE Systems. The Alliance provides access to research for companies and a framework for members to engage consultancy advice. IfM also hosts the Digital Supply Chains Consortium, transferring supply-chain research into practice. CUED received Boeing Supplier of the Year awards in 2017 and 2018.

4.4 Public Engagement

DMSM

DMSM has a strong track record, and examples during the assessment period include over 70 public engagement and outreach lectures both within the UK and abroad (e.g. through the auspices of the IoP, CPS, Royal Society). Further examples include the Royal Society Summer Exhibition in 2015 (led by **Rae**) entitled 'Engineering Atoms' and seen by ~14,000 members of the public, including 2,500 school students. DMSM is also active in shaping public policy with 8 staff on Research Council committees. **Oliver** spoke to the Science and Technology Select Committee about the impact of funding policies on the diversity of the STEM community.

CEB

The Department employs a Communications Manager who promotes research outputs through news on the website, social media channels, external newsletters and press releases. Departmental research has featured on national and local TV news programmes, radio programmes and online trade media websites. CEB takes part in the *Cambridge Science Festival* every year. **Fruk** is the Public Engagement Coordinator for the School of Technology, a Member of UCAM's Public Engagement Advisory Group to the Vice-Chancellor, a regular contributor to BBC Radio Cambridgeshire, and has organised public science-art exhibitions in the UK and Germany, such as the *3D Molecules that Changed the World* exhibition in 2016. **Stranks** has developed a Primary Schools Energy-Mapping Challenge to encourage pupils in areas of high socio-economic deprivation to explore renewable energy generation. **Molloy** from 2015–18 ran *Science Makers* at the Cambridge Makespace as a monthly hands-on public session for 15–25 people, building low-cost scientific instrumentation. In 2016, she founded *Cambridge Biomakespace*, a community laboratory attracting 50 members and has hosted >100 public talks and workshops.

The yearly *research team challenges* offered to PhD student cohorts by the *Sensors* CDT have generated global impact and influenced national policy, e.g. in Argentina and Kenya, and have led to numerous awards, including the 2019 UCAM VC award for collaboration and impact.

CUED

The Department publicises its research and engages with the public through open events, a dynamic web presence, social media and newsletters. Engagement events include the "Cambridge Robogals" robotics events for school-aged girls, engineering summer schools and masterclasses for school-aged children, the Climate Change Lecture Series and outreach events on International Women in Engineering Day. Members of CUED have presented their research for non-specialist audiences on the BBC, ITV and The Naked Scientist, and at events including the Hay Festival, Cambridge Science Festival, Royal Society Summer Science Exhibition, Pint of Science Festival, Cheltenham Science Festival, TedX, and British Consulate Science Café. **Hunt** won the 2015 RAEng Rooke Award for the public promotion of engineering. Public engagement is supported by the CUED Communication and Marketing Office and a full-time Outreach Officer. The Research Office provides training and guidance for staff on communicating research to the public.

4.5 Contributions to the Discipline

International

Academic staff have chaired or served on Boards or Review Committees for academic institutions and funding agencies worldwide, including: AMMRF (Australia), NCEM, LBNL, Oak Ridge National Laboratory, NSF Materials Science Division Committee of Advisors, SLAC Proposal Review Boards, NASA 2040 Vision Panel for Materials Strategy (National Academies, USA), ERC Advanced Researcher Grants Panels, Helmholtz Centrum Assessor, Danish National Research Foundation, Finnish Academy of Science, Bangalore-Cambridge Innovation Network (India), Swiss National Science Foundation, Max Planck Institute for Polymer Research, Scientific Advisory Board Max Planck Institute for Molecular Medicine (Germany), NTNU Trondheim Research Evaluation Committee (Norway), Tyndall National Institute (Ireland), Strategic Advisory Board (SRAB) of the Austrian Institute of Technology, International Board of the MacDiarmid

Institute for Advanced Materials (New Zealand). Staff have also served on committees of the Federation of European Materials Societies, and the Materials Research Society (US).

Leadership and Membership of Major Committees – UK

Staff have chaired or served on committees for EPSRC, IOM3, IOP, RAEng, Royal Society and Royal Society of Chemistry. Highlights include members of the UoA being: Treasurer and Vice-President of the Royal Society; Chair and Member of Royal Society URF Panel A, and Royal Society Newton Fellowship Panel; President and Senior Vice-President IOM3; President and Past-President European Microscopy Society; Chair Biomedical Engineering Panel, RAEng; Chair Biomedical Applications Division, IOM3; President of the RAEng; President of the Institution of Civil Engineers; Chair, ISIS Facility Board; Members of the Queen Elizabeth Prize for Engineering Search Group; and STFC Physical Sciences and Engineering Advisory Panel (Chair, Deputy Chair and Member).

Contributions to Government

MacKay was Chief Scientific Adviser, Department of Energy and Climate Change until October 2014, and knighted in 2016. **Dowling** served on the Prime Minister's Council of Science and Technology (2014-19); **Mair** serves on the House of Lords Select Committee on Science and Technology; **Evans** is co-Chair of the Parliamentary Manufacturing Commission; **Dowling** was a non-executive board member of the Department for Business Innovation and Skills (BIS, 2014-2016) and the Board for BEIS (2017-18); **Guthrie** served on the Scrutiny Panel for Thames Water and the Environment Agency's Local Flood Risk Research Steering Group; **Neely** served on the Blackett Review Expert Team for GO-Science Report on Services; **Girolami** serves on the Defence Science Executive Committee of the Ministry of Defence; **Weller** serves on the board of the Centre for Data Ethics and Innovation; **Shwageraus** serves on the Nuclear Innovation and Research Advisory Board. The Review of Business-University Research Collaborations (2015) was chaired by **Dowling**. **Gladden** is Executive Chair of EPSRC. **Christie** is on the Government's Environmental Decontamination Committee. **Clarkson** chairs Sub-Panel 12 of REF 2021.

Industrial Boards

Staff are supported in taking on industrial advisory roles. Examples include **Dowling** chairing the BP Technical Advisory Council and **Fleck** chairing the Rolls-Royce Manufacturing and Structures Scientific Advisory Board. Over 60 members of the UoA have held company directorships, spanning start-ups through to multinationals (e.g. BP plc, Smiths Group plc).

4.6 Indicators of Wider Influence and Contribution

Members of the Departments have given over 330 invited plenary/keynote lectures at major international conferences and prestigious named lectures. They are editors/associate editors of 74 journals, and members of over 230 editorial boards.

The UoA has 17 Fellows of the Royal Society including **Midgley (**elected 2014), **Robertson** and **Ghahramani** (2015) and **Deshpande** and **Young** (2020); and 21 Fellows of the Royal Academy of Engineering including **Fitzgerald** (elected 2014), **Udrea** (2015), **Woodland** (2016), **Allwood**, **Prager** and **Purnell** (2017), **Langley** and **Neely** (2018).

The UoA has 3 (2 new) members of the US National Academy of Engineering, 1 Fellow of American Association for Advancement of Science, 1 Foreign Member of the Chinese Academy of Engineering, 1 Fellow of the American Institute of Aeronautics and Astronautics, 1 Foreign Associate of the French Academy of Sciences and 1 Foreign Fellow National Academy of Sciences, India, 3 Fellows of the Royal Aeronautical Society, 9 (6 new) Fellows of the Institution

of Engineering and Technology, 5 (1 new) Fellows of the Institute of Physics, 2 Fellows of the Institution of Mechanical Engineers, 8 Fellows of the Institution of Chemical Engineers, 10 Fellows of the Institute of Electrical and Electronics Engineers, 1 Fellow of the Institution of Civil Engineers, 1 Fellow of the Society for Industrial and Applied Mathematics, 1 Fellow of the International Speech Communication Association, 2 Fellows of the Materials Research Society, 2 members of Academia Europaea, 2 members of the European Academy of Sciences, 2 Fellows of the Royal Society of Chemistry, 1 Fellow of IoM3, 1 Fellow of the Royal Microscopical Society.

Honours include: **Dowling** OM (2016), **Gladden** DBE for services to chemical engineering (2020), **Bhadeshia** knighted for services to science and technology (2015), **Cheetham** knighted (2020), **Best** CBE for services to biomaterials engineering (2017), **Schooling** and **Neely** OBEs for services to engineering and digital construction (2019 and 2020, respectively), **Ferrari** Knight Officer of the Order of the Star of Italy (2017), **Glowacki** Knight Cross of Polonia Restituta for services to science (2014).

Major prizes and awards from learned societies and professional bodies include: *IoP* (Rayleigh Silver Medal, Joule Medal, Rosalind Franklin Medal and Prize), *Royal Society* (Royal Medal (×2), Wolfson Research Merit Award, Mullard Medal), *IoM3* (Gold award, Futers Gold Medal, Cook-Ablett Award, Kroll Medal (×2), Griffith Medal (×2)), *AWT Germany* (Martens Medal), *Learned Society of Wales* (Dillwyn Medal), *Royal Society of Chemistry* (MacroGroup Young Researchers Medal), *UK Society for Biomaterials* (President's Prize (×2)), *UK MRC* (Suffrage Science Award (×2)), *RAEng* (Armourers and Brasiers Medal, Mitchell Award), *IEEE* (Wong Medal, James Flanagan Speech and Audio Processing Award), *RMS* (Medal for Innovation in Applied Microscopy), *European Academy of Sciences* (Pascal Medal), *American Institute of Chemists* (Chemical Pioneer Award), *ASM International* (Saveur Achievement Award), *IFW Dresden* (Leibniz Medal), *ASM International* (deMille Campbell Memorial Lectureship), *IChemE* (Young Researcher Award), *The Chemical College Board of Engineers Australia* (Brodie Medal), *German Society for Aeronautics and Astronautics* (Prandtl Ring), Engineering Professors' Council President's Prize, *IMechE* (Watt International Gold Medal), *Royal Philosophical Society of Glasgow* (Kelvin Medal), *Institute of Acoustics* (Engineering Medal), Sir Misha Black Medal for Distinguished Services to Design Education, *Institution of Civil Engineers* (Telford Prize, President's Medal), *Gruber Foundation* (Gruber International Prize), *British Liquid Crystal Society* (Hilsum Medal), *American Chemical Society* (Nano Award Lectureship), *American Carbon Society* (Pettinos Award), *Institution of Engineering and Technology* (Achievement Medal for Manufacturing), *ASME* (Koiter Medal), EUROMECH Solid Mechanics Prize, *International Union of Theoretical and Applied Mechanics* (Hill Prize).

During the assessment period, members have been awarded significant grants and working fellowships: ERC grants (×7), Royal Commission of 1851 Fellowships (×4), EPSRC Fellowships (×6), UKRI Future Leaders Fellowship (1), MRC Career Development Award (1), Royal Academy of Engineering Fellowships (×5), Wellcome Trust Fellowships (×3), Leverhulme Trust Fellowships (×3) and Marie Curie Fellowships (×17), Helmholtz Society International Fellowship (1), Leverhulme Trust/RAEng Senior Research Fellowship (1), Winton Advanced Research Fellowship (1); RAEng Chair in Emerging Technologies (1).

Members of the UoA led and contributed to numerous external EDI programmes, including *Women in Science* and *Women in Aerospace* events, *Women in Graphene*, EDI at the Alan Turing Institute. **Dowling** is patron of the Women's Engineering Society.

Recognitions of ECRs and postdoctoral researchers include for example: *Metals Journal* (Young Investigator Award), *Rank Prize Fund* (Lecturer Prize), *World Economic Forum* (Young Scientist Award), USERN Prize in Physical Sciences 2018, awarded by the *UNESCO Universal Scientific*

Education and Research Network, *Spanish Royal Society of Physics* (Young Researcher Experimental Physics Prize), *Forbes Magazine* (*30 under 30* (×2)).