Institution: The Open University

Unit of Assessment: B12 Engineering

1. Unit context and structure, research and impact strategy

a. Context

The Open University (OU) B12 Engineering unit of assessment (UOA) is returning 24 (23.4 FTE) Category A Staff (CAS) to REF2021. The unit currently has 10 Research Associates/Assistants (RA), 29 Post-Graduate Research Students (PGRS) and 13 technical support staff working alongside the academic staff to deliver its research. The unit has four research themes:

Materials Engineering (ME, 9 CAS)
Functional Materials (FM, 7 CAS)
Energy Engineering (EE, 4 CAS)
Engineering Design (ED, 4 CAS)

Unit activities in all themes cover a range of commercial engineering sectors. We aspire to achieve science and engineering leadership in wide subject areas: from synthesis of graphene quantum dots to structural integrity of nuclear power plants and from water purification to low energy construction.

Unit staff are encouraged to form interdisciplinary collaborations, not just internally, but nationally and internationally. Most academics are active in two or more of the themes; most of our research projects and outputs are collaborations with external colleagues from a variety of sectors, including other HEIs, research institutes and industrial companies.

Over the current REF period, the aim of B12 unit has focused on the expansion of its scope to ensure intellectual breadth and rigour across all our subject areas in order to address contemporary and future challenges. In support of this strategy, we have hired 12 new academic members of staff at different levels of seniority, from Professor to Lecturer, accounting for 50% of the submission and ensuring sustainability of the unit's research base.

b. Structure

Since REF 2014, the OU has undergone a re-structuring exercise, amalgamating two Faculties (of Science and of Maths, Computing and Technology) to form the Faculty of Science, Technology, Engineering and Mathematics (STEM). STEM has six Schools, and B12 staff are located across two Schools: 19 staff are in the School of Engineering & Innovation (E&I) and 5 in the School of Life, Health & Chemical Sciences (LHCS). The research of the B12 unit is supported by 10 technicians in the School of E&I and 3 in LHCS, with further support provided at Faculty level.

The research laboratories and library are sited at the OU Walton Hall Campus in Milton Keynes (MK), which is also home to our PGRS.

The rich nature of the research environment in which B12 staff work, its breadth and interdisciplinary character, is reflected not only by the fact that members from different schools work on the same area and return to the same REF UOA, but also that members from the same school return to different REF UOAs. For example, academic staff in the School of E&I are returned to 6 different REF units (B07, B12, C22, C23, D32 and D33) and those in LHCS are submitted to A03, B09 and B12.

There is considerable collaboration and cross-fertilisation of ideas between these research units and engineering which enhances the novelty and impact of the work within B12. An example of intra-unit collaboration involves **Collinson** from the School of LHCS and **Forsey** from the School of E&I who have jointly secured a grant of £71.8k from AHRC to investigate the effects of detergent use on the historic interpretation, understanding and conservation of museum textiles, in collaboration with the V&A museum.

c. Research strategy

The research vision of the OU B12 Engineering unit is based on the OU, STEM and Schools' vision for research and enterprise and rests on three aspirations *to inform*, *to inspire* and *to influence*. Our activities *inform* curriculum*, inspire* staff, students and the public and *influence* engineering practitioners.

Our strategic objectives are set within the Open University's founding principle of "to be open to people, places, methods and ideas". Research excellence and knowledge exchange are fundamental to this principle.

The strategic objectives are:

- To innovate novel science and technology within all engineering disciplines, enabling fundamental understanding of engineering problems
- To provide sustainable methods and solutions for research, industry and living environments
- To train a new generation of engineers to address key societal challenges, and
- To promote new findings openly via publication, collaboration and knowledge transfer

The objectives are ambitious, but the unit's combination of research excellence and open knowledge transfer has positioned B12 Engineering at the OU in a place for innovation and impact, geared to carry the research strategy forward.

Our objectives are already showing evidence of success:

- To increase FTEs in all themes to a level that generates a stimulating environment for the research activity. The research areas have both broadened and deepened in overall B12 engineering.

  Engineering Design (ED): This theme was expanded significantly by appointing **Neighbour**, **Lockett** and **Moncaster** to complement **Taherzadeh**. Neighbour was previously a chair and the Head of School of Engineering and the Built Environment at Birmingham City University. The research expertise in ED has been expanded from the design of vibration and acoustics to include the design in additive manufacture, sustainability engineering and low/zero carbon buildings.

  Energy Engineering (EE): Psoma and **Varagnolo** were appointed to reinforce this theme. They work alongside **Nuttall** and **Krishnamurthy** on innovation management and policy applied to energy and power engineering, energy storage using supercapacitors, energy harvesting by solar and piezoelectric technologies, optical biosensors, organic photovoltaic devices and electrodes. **Professor Krishnamurthy** was promoted to a Chair of Energy Technology in this REF period. The research activities have been strengthened to new levels.

  Functional Materials (FM): The theme has been strengthened at all levels by the appointments of **Bowen**, **Golrokhi**, **Goolaup** and **Power** to complement **Bruce**, **Crabb** and **Heeley**. The theme continues research activities in nanoparticle catalysis, electronic device and energy harvesting polymers and polymetric materials. The new staff members add fresh research topics in surface and interface materials, nanoelectronics, bacteria and bone growth, and quantum dot fabrication.

  Materials Engineering (ME): During the REF period **Forsey**, **Jazaeri** and **Qin** were appointed to work alongside **Bouchard**, **Collinson**, **Gungor**, **Hosseinzadeh**, **Moat** and **Shirzadi** in this theme. **Professor Qin**, formerly at Imperial College London, was appointed to a Chair in Advanced Materials Engineering. The theme remains strong in structural integrity, residual stress, creep, diffusion bonding, mechanics of materials and recycling technologies. New research activities in materials processing using electromagnetic field, digital image correlation analysis and materials for energy applications have been initiated by the newly appointed academics.

- To build our capacity in distinctive research through increased and widened public and stakeholder engagement with our research.

  During the REF period the members in B12 have carried out 78 research projects funded by government agencies, industrial companies and charities. These include 28 projects from UK Research and Innovation: 24 from EPSRC and 4 from BBSRC. Other projects are from the European Commission, Royal Academy of Engineering, Royal Society, Technology Strategy Board, British Council, Innovate UK, Research England, Department for Transport, Chartered Institution of Waste Management and industrial companies from UK and overseas. The industrial funders include EDF Energy, Rolls Royce, Mitsubishi, Shell and 12 other companies.

  The OU B12 members have successfully completed 62 consultancy projects in the REF period, using our expertise to help other research and industrial institutes in the UK and overseas. Some projects help industrial companies to carry out upscale testing of our research results for the application in production lines. Example includes a project to help Materials Processing Institute (MPI) to carry out pilot plant trial of our clean-steel green processing technology to expel oxide inclusions using electric field, the outcome has convinced TATA Steel Europe to set further trial at production line. Most projects are to help industrial partners in the decision-making process of their engineering manufacturing by, for example, providing information on the distribution and development of residual stress in engineering components. These projects were funded by 24 companies and 4 other universities. The Unit's top 4 industrial funders in terms of project numbers are Rolls Royce plc (11 projects), CETIM (8 projects), AREVA NP (6 projects) and TWI Ltd (6 projects).

  B12 members have participated actively in the initiation of strategic research organized by leading national and international companies. We are one of six UK universities listed as Scientific Network partners by the Materials Ageing Institute (MAI-SN) at EDF in France, alongside Imperial College London, Oxford University, University of Bristol, University of Manchester and University of Strathclyde, to address the ageing problem in nuclear plants. Funding was received from MAI-SN to fund a project for a postdoctoral researcher. We are one of ten UK HEIs working with Lucideon to develop the National Advanced Sintering Centre to deliver a step change in the UK's research and development capacity for sintering technologies, bringing technologies quickly to market.

- To develop our large-scale, external research collaborations and doctoral training partnerships.

  We are members of two EPSRC Centres for Doctoral Training (CDT). One is the EPSRC CDT in Nuclear Energy: Building UK Civil Nuclear Skills for Global Markets for the period between 2014 and 2022. **Nuttall** is the Co-I of this EPSRC CDT in collaboration with Imperial College London and the University of Cambridge. The second is the EPSRC CDT in Nuclear Energy Futures for the period between 2019 and 2027. B12 members **Gungor** and **Hosseinzadeh** are Co-Is in collaboration with Imperial College, Cambridge, Bristol and Bangor Universities.

  Members in B12 unit have developed and participated in large research collaborations with academia in other UK and EU organizations. Recent EPSRC projects include a **Bouchard**-led £1.15 million project in collaboration with Oxford and Bristol Universities and a **Moat**-led £651k project in collaboration with Manchester University. For the large collaborative projects from the European Commission, **Qin** is a Co-I of a project of over €2.28 million (EU RFCS project reference number: 847269) in collaboration with 6 EU companies and the University of Warwick. **Krishnamurthy** is a Co-I of €8.5 million project (EU project reference number: 958491) in collaboration with 17 partners from 12 EU countries that started in November 2020.

  Members in B12 have secured research grants for further international collaborations beyond UK and EU. Examples include UK-China collaborative research funded by the Royal Society's Newton Advanced Fellowship scheme (NA150320), UK-India

collaborative research funded by EPSRC and UKIERI, and UK-Japan collaboration funded by EPSRC.

92% of our outputs are collaborative with external research organisations. The co-authors are from the UK as well as 15 overseas countries in Oceania, Asia, Europe and North America.

- To ensure the availability of high-quality facilities for the production of excellent research outputs.

  B12 members have a tradition, in collaboration with technical staff, to design new facilities, apply facilities to new research field and develop software to enable new functionalities. We have some unique facilities in the country. Examples include the 3D Digital Image Correlation (DIC) creep rigs that allow long term 3D DIC monitoring of creep, integrated rigs to allow in-situ observation of reactive fluid under pulsed electric field, and atmospheric pressure plasma printing facility.

  The School has invested £1.7 million and the Faculty spent nearly £1 million to support research in B12 UOA since 2014. A major portion has been invested to purchase new facilities and cover service contracts for major instruments. Our members are encouraged to apply for equipment grants. The site runs facilities for chemical characterization, material processing, physical characterisation, mechanical tester, thermal analysis and electromagnetic analysis.

  B12 members have secured £2.6 million in-kind support via beam-time awards and use of other organisations' research facilities since 2014. Accessing national facilities, such as ISIS neutron source and Diamond light source, has contributed to our research. For example, a project involves the use of neutron diffraction to determine the strain distribution in alloys. Some projects include the allowance to use national supercomputers ARCHER and the recently upgraded ARCHER2 such as the UKCOMES project funded by EPSRC to use these national supercomputers to simulate engineering fluids.

  Our innovative and award-winning openSTEM Labs established during the REF period, provide remote access to many research facilities. Researchers are able to operate the facilities using a computer or mobile phone in their home. **Lockett** is the current director of openSTEM Labs. During the Covid-19 pandemic, our experimental works, such as those using electron scanning microscope, have not been disrupted and proved to be routinely accessed for research projects.

- To maximise the synergies between research, our curriculum and our teaching.

  During the REF period, the OU B12 members have secured 4 external grants to promote research into teaching and curriculum in Engineering. Examples include the Transforming Engineering Culture project led by **Moncaster** and funded by the Royal Academy of Engineering and the development of an open access remote photovoltaics laboratory led by **Krishnamurthy** and funded by H2020 European Commission. Many B12 members lead one or several internally funded eSTEeM scholarships to contribute and maximise the synergies.

Future Strategy (next 5 years): Having transformed our research from the previous focus on metallurgy and chemical engineering in REF2014 to a unit with broad and rigorous activities across all our subject areas, our strategic aims for the next 5 years are:

a) to support the research aspirations in all themes by recruiting, fostering and maintaining a sustainable staff-base
b) to support the development of external collaborations and stakeholder engagement to enhance and translate our research
c) to grow our postgraduate research student community via membership of further CDTs, DTPs and Industrial case study studentships
d) to ensure our instrumentation continues to support our research excellence
e) to improve the economic and societal impact from our research.

d. Impact strategy

The impact strategies of B12 Engineering are:

- To identify emerging engineering needs in the UK and around the World
- To collaborate with stakeholders, scientists and R&Ds to address the challenges, and
- To promote scientific innovation to society and community

Our impact is promoted by an open research environment and wider contributions to the economy and society.

- An open research environment.

  Over the current REF period, B12 members have published 444 journal papers, 12 books, and 51 book-chapters. All our members are required to upload copies of their papers to Open Research Online (ORO) and research students to upload an electronic copy of their thesis. Complementary with ORO is the University's data repository, Open Research Data Online (ORDO), enabling researchers to share and publish their data and obtain a digital object identifier. B12 members are encouraged to upload all the data in relevant to the publication to the site for free access. The audience can access the data according to the statement in the publication such as "the datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request". The OU has a dedicated Research Data Management Librarian, who advises staff and students. As part of their training, PGRs are expected to complete a short module on *Research Data Management*, part of which involves completion of a Data Management Plan.

- Wider Contributions to the Economy and Society.

  Our research contributes to the economy and society including the provision of patents, establishment of start-up and spin-out companies to provide high-tech services, contribution to new standards and new policy, involvement in build-up knowledge transfer partnerships (KTP), and engagement with external organizations and industries to promote the technological advances. Examples of evidence of success include:

  Patents: **Goolaup's** non-volatile logic device obtained US patents (US 9,431,599 B2) in 2016. **Varagnolo's** research on selective deposition of metallic layers was filed for a UK patent in 2018 (UK patent application No: 1817037.3).

  Start-up and spin-out: **Bouchard** founded Stress-Space Ltd which was registered in 2017 and achieved a turnover of £232k in 2019. **Lockett's** work contributed to the basis of the software tool now being marketed as WAAMPlanner in Cranfield University's spin-out company WAAM3D.

  Contributions to new standards and new policy: **Lockett's** research in design for additive manufacturing contributed to the development of an ASTM standard and she was a member of the committee that developed the guide and authored parts of it. **Nuttall** contributed to a European Commission funded advisory process constructed to support policy for the 7-year Horizon 2020 Euratom Fission Research and Training Programme which totalled €877m. His research directly led to the inclusion of social science into the research portfolio for the first time. The social science funded via this mechanism is valued at approximately €10m. **Bouchard** is a founder member of the NeT (Network on Neutron Techniques Standardization for Structural Integrity) Steering Group. He served on the ISO TC135/SC5 working group that successfully adopted Technical Specification ISO/TS 21432: Non-destructive testing - Standard test method for determining residual stresses by neutron diffraction as a full ISO Standard. He also sits on two R6 Procedure Panel sub-groups on Weld Residual Stress Profiles and Weld Simulation Benchmarks and Guidelines.

  Contributions to industry: **Bruce's** work increased WJ R&D capacity and Cornelius developed personal care products for new markets. **Nuttall's** research has influenced the relatively new emergence of small start-up companies utilising nuclear fusion

technology. In 2020, together with his OU PhD student and Japanese colleagues, **Nuttall** edited the book 'Commercialising Fusion Energy' (IOPP) and contributed to several chapters. **Shirzadi's** research led to a new method for manufacturing a bi-metal adapter needed for X-ray sterilisers in cooperation with Atlas Technologies in USA and a new method for melt spinning developed for Edmund Bühler GmbH – Hechingen in Germany. Three KTP projects have bolstered our partnership with chemical and pharmaceutical companies, leading to the development of new products and processes as well as gaining reputation in the field. A number of B12 members support the OU's StressMap unit that has delivered £1.5m residual stress measurement services to clients since 2013.

Engaged research: **Bowen's** research was featured in Nunano (1, 2) Medium, Bou, Chemistryworld and ACS. **Bruce's** research was cited in WJ industrial magazines. **Moncaster's** research was acknowledged in the articles published by the Institution of Structural Engineers 2020, International Energy Agency 2019, Athena Sustainable Materials Institute 2019 White Paper, Royal Institution of Chartered Surveyors 2017 and the World Green Building Council report at 2019. She was PI on the EPSRC/Innovate project which produced the Royal Institution of Chartered Surveyors (2017) Professional Statement on whole life carbon assessment for the built environment (1st edition), which in turn is summarised by the Royal Institute of British Architects.

- **Regional and National research priorities**

  OU is a Four Nations university, with centres in Belfast, Cardiff and Edinburgh as well as in Milton Keynes. We have developed strong links with the different administrations and have advised on research priorities and strategies for their achievement. The nature of the OU has also facilitated our relations with regional business communities and allowed us to build a variety of collaborations. For example, **Nuttall** spoke at the Scottish Parliament on 25 November 2015 on "Nuclear Developments: UK, EU and Globally" and published a book chapter relating to energy policy in Scotland entitled "Scotland, Nuclear Energy Policy and Independence" in 2017. **Psoma** has been awarded a Knowledge Transfer Voucher in collaboration with the Scotch Whisky Research Institute to develop a biosensor for whisky industry.

Our impact strategic aims for the next 5 years are:

a) to collaborate with the scientific and industrial community to develop new products, new processes, new methods, new standards and new assessment to address the global challenges such as carbon neutralization, resource sustainability and energy strategy.
b) to collaborate with UK stakeholders to contribute to the development of a productive, healthy, resilient and connected nation
c) to work with companies and trade bodies to understand their requirement and collaboratively develop the solutions
d) to promote engineering through an open teaching and research environment to widen our contributions to the economy and society
e) to explore how best to support the development of effective impact

2. People

a. Staffing strategy

The objectives in the REF period have been to expand the scope of research across all our subject areas, to foster an exciting research environment and to develop the potential of all our staff. We have lost some key research players to other universities, but have been able to recruit high quality staff in their place, as described in section 1. The departure of academic staff in Materials Engineering and Functional Materials has been more than compensated by the recruitment of **Bowen**, **Forsey**, **Jazaeri**, **Neighbour**, **Power**, **Qin** and **Varagnolo**. The expertise of the new staff has not only enhanced the existing research fields but broadened our research scope. The other recruitment for the unit corresponds to our change in research strategy and establishment of Engineering Design and Energy Engineering. Among the current members

returned to REF2021 B12, four are professors, 12 are senior lecturers, seven are lecturers and one is staff tutor.

b. Recruitment and progression

All academic and research positions are advertised in both the University's vacancies webpage and at least one external site (e.g. https://www.jobs.ac.uk). Both contain a full description of the role, benefits, and the application procedure. The Resourcing Hub checks and approves every advertisement to ensure fairness and abide by employment regulations. We receive a good number of applicants for each academic position. For example, the recently advertised lectureship (Ref No. 16702) received 42 applicants.

Members of the selection panels are required to complete an on-line module "Recruitment, Selection and Interviewing at The Open University". The module explains how to reduce Unconscious Bias and embed equality and diversity in the recruitment process, as well as covering interviewing skills. The interview process comprises a panel assessment and a presentation to researchers and academic staff. Where disabilities are flagged in the application form, adjustments for interviews are organised in advance and in confidence through contact between the administrative-support team and the candidate. Feedback from both sessions are obtained before any offers of appointment are made. The Resourcing Hub checks the constitution of selection panels to ensure the requirements for equality, diversity and inclusion are met.

All new members of staff receive an extensive induction and are allocated a probation supervisor and a mentor. Once the probation period is concluded, all staff members are assigned an appraiser to carry out annual appraisals and a 6-month appraisal review meeting. The appraiser is nominated by the Head of School annually but the appraisees have the right to reject the nominated one and request an alternative appraiser. The appraisal procedure is called the Career Development and Staff Appraisal system (CDSA). The purpose is partly to reflect on past performance and partly to look at future performance. During the meeting, objectives are agreed and, development and training needs are identified. We have a well-defined reward and promotion system to support career progression. A meeting of all School appraisers held after CDSA to recommend merit awards and promotions. Recommendations are further considered by Faculty and University groups and awards made. Workshops providing advice and guidance on how to gain promotion from lecturer to senior lecturer and from senior lecturer to professor are held twice a year. During the REF period 1 member of staff (**Krishnamurthy**) was promoted from senior lecturer to professor, 1 (**Qin**) was appointed as professor from senior lecturer in another university, 6 were promoted from lecturer to senior lecturer and 2 were appointed as senior lecturer.

c. Staff development

The Schools provide funds for consultancy, travel & subsistence, attending conferences, purchasing of small equipment and hospitality to support the initiation of research, collaboration and impact promotion. The Faculty provides free access to research facilities to academic members without secured research grants. All staff undertake mandatory training on Information Security Awareness, General Data Protection Regulation, Prevent Counter Terrorism and Safeguarding.

The STEM Research, Enterprise and Scholarship Team is comprised of over 15 staff who collectively provide the STEM faculty with the professional services that are needed to deliver to the strategic and operational requirements to achieve our research objectives, ensuring compliance with faculty and university processes and governance. The team compiles and distributes a weekly *Funding Newsletter* to all academic members to inform them of current funding opportunities, provides active support and advice in the development of external bids for funding and administration and in the management of awarded externally funded research projects. Support is also provided for the administration of PhD studentships; enterprise and partnership development; external engagement; and scholarship activity. The Faculty has a dedicated Impact Manager, who works with colleagues to develop and strengthen impact

pathways in the development of a bid and further provides support in the progression, communication and implementation of pathways for awarded projects.

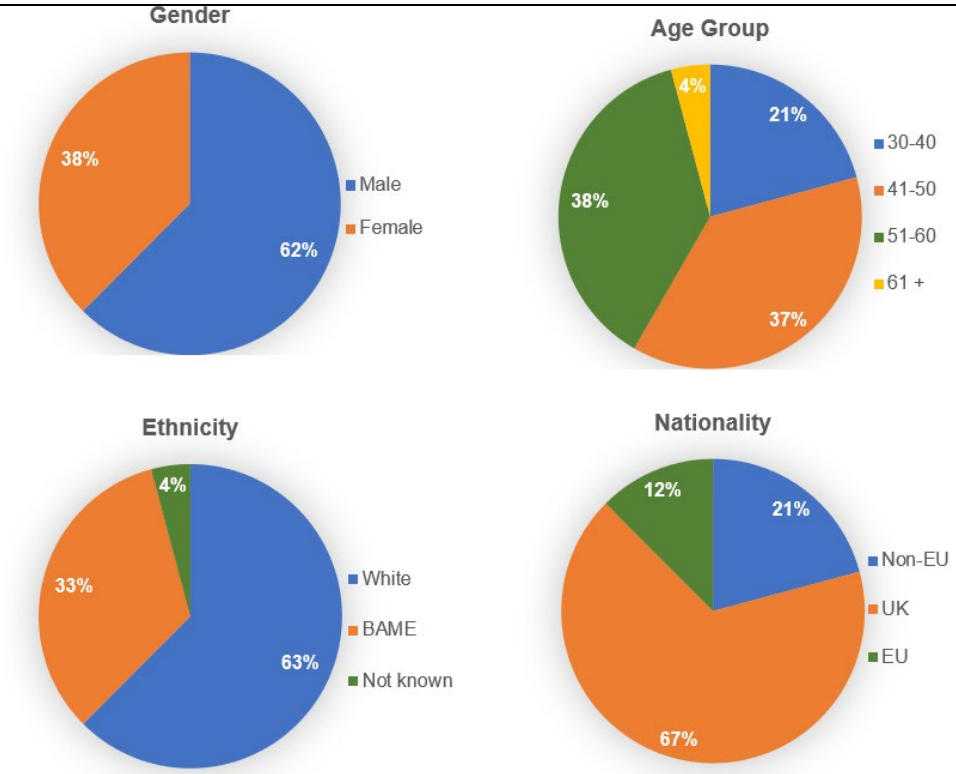
We offer a range of agile working options, including compressed hours, staggered hours, home working, part-time working and job sharing. All staff are provided with facilities to work from home. The University provides Skype for Business and Microsoft Teams systems to enable staff members to access their office telephone and hold meeting remotely. The majority of meeting and seminar rooms are set up with equipment to enable remote participants to join in easily. Staff are trained to use the equipment and to chair meetings to ensure that remote participants are fully included. All School and Faculty meetings and seminars provide an online access as a default.

The University has an active flexible working policy which allows staff to request, for example, periods of part-time working on return from illness. In addition to the maternity policy it includes provision for Keeping-in-Touch days and an entitlement to focus on research activities immediately after return. During the Covid-19 pandemic period, the University had a generous contingency leave system in place to ensure that all staff could continue to work around caring responsibilities such as childcare.

d. Support for staff on equality, diversity and inclusivity

We have a diverse staff and researcher profile in terms of nationality, ethnicity, age and gender. The current staff profile of the B12 unit is shown in the figure below, being reasonably balanced. All members of staff are required to complete an Equality Essentials course, and the certificate needs to be refreshed every 24 months. Nine of our 24 B12 staff are female. The proportion is higher than the national average reported by the Women's Engineering Society (12.37%) according to the Engineering UK 2018 reports. 33% of B12 members are from other countries, showing we are an international research unit.

The Open University received its Institutional Athena SWAN Bronze Award in 2013 and renewed in 2016. Both of the Schools in which B12 members are based were awarded Departmental Athena SWAN Bronze status in 2016. E&I have recently been awarded Athena SWAN silver status. Several female staff have undertaken AdvanceHE's 'Aurora' leadership development programme to enable them to fulfil their potential. B12 member, **Morris**, has been recognised for her work in challenging gender stereotypes in engineering with a Top 50 Women in Engineering Award (WE50) in 2018. **Moncaster** gave evidence at the Palace of Westminster to the All-Party Parliamentary Group on Excellence in the Built Environment on increasing gender diversity in construction in June 2019. **Moncaster** and **Morris** jointly edited a special issue of the International Journal of Gender, Science and Technology on Gender and Intersectionality in Engineering in 2019.



The formation of the OU B12 panel has considered EDI principles in term of gender, ethnicity and career experience, as well as research discipline. Three panel members (**Heeley**, **Lockett** and **Moncaster**) are female, four panel members, including both the panel chair and impact case leader, are BAME. All panel members have completed Equality, Diversity and Unconscious Bias training before undertaking any assessment tasks. The selection of B12 returned members followed the University Code of Practise and was based purely on the criteria for significant responsibility for research and research independence. Each B12 member had equal opportunity to provide up to five representative outputs in the REF period. Each output was assessed by at least 3 panel members. For the papers ranked to the same score, the balance of gender and career stage has been considered alongside research discipline to ensure that our output list reflects the depth, breadth and diversity of our submitted researchers.

e. Early career academics

Early career academics are given privileged access to school and faculty funded PhD studentships. All new members of staff receive an extensive induction and are allocated a probation supervisor and a mentor. A comprehensive programme of training opportunities is provided, including training for supervising postgraduates and research assistants, writing research proposals and developing research impacts. Training is provided online and via workshops. Many early career academics are able to secure their research grants within three years. For example, **Hosseinzadeh** received her EPSRC First Grant. **Forsey** and **Jazaeri** became CO-I of EPSRC and other grants.

f. Postdoctoral researchers

B12 members currently supervise 10 postdoctoral researchers (PDRAs). The PDRAs are funded by external research grants and employed on fixed-term contracts (FTCs). They all participate in the annual CDSA appraisal process in the same way as central academic staff. All training events and workshops are open for PDRAs to attend. They are encouraged to develop independent research proposals and to bid for eligible funding opportunities. The OU Engineering group runs an annual residential school and encourages the PDRAs to apply for tutorial positions to develop their teaching skills. Some PDRAs have participated in module development and presentation. They are paid at the same rate as associate lecturers (ALs, see institutional environment) for this work.

Our PDRA recruitment process is very competitive. For example, a recent position of Research Associate in Materials received 80 applicants. Some PDRAs have received offers of academic positions immediately on completion of their fixed term contract. Examples in the current REF period include Dr. Xinfang Zhang secured a full professorship at University of Science and Technology in Beijing and recently became an Associate Dean. Dr. Yan Zhao accepted an offer of full professorship from Beijing Institute of Technology at Chongqing. Dr. Mannan Mehta secured an Assistant Professor position in Indian Institute of Technology Delhi. Dr Abdullah Mamun was appointed EDF Fellow in Nuclear Structural Integrity at the University of Bristol, and two other PDRAs (Forsey and Jazaeri) were offered academic positions at the OU. Some PDRAs joined industry and have taken senior research roles. For example, Dr. Binyan joined TWI Ltd in Cambridge as a Senior Project Leader.

g. Postgraduate students

B12 has studentships from a range of sources, including EPSRC DTC, AHRC CDP, industrial CASE, EPSRC, EU, industry, self-funded and those funded by Schools and Faculty for B12 UOA. B12 currently has 29 registered PhD students: 24 in the School of E&I and 5 in LHCS. Nine of them are female. In the current REF period, we have supervised to completion 33 PhD students.

All the studentships are advertised externally for open and fair competition. The supervisory team comprises at least two active academic members. Projects with external partners often include an external or industrial member. Each student is assigned a third-party monitor for independent counsel. B12 research supervisors are required to complete a training program named Supervising Doctoral Studies. The programme was designed to help both new and experienced research supervisors to develop their ability to effectively mentor doctoral candidates. All the students are overseen by a group of 5 Postgraduate Research Tutors who ensure compliance with the OU's Research Degree Regulations.

The postgraduates start their study journey with a two day induction program. Day one includes an introduction to postgraduate research, the core research skills and methods training, library services, and the Graduate School Network. Day two includes some student network activities and meeting with supervisors and staff members. Further discipline-specific induction on the use of various laboratories and facilities, including health and safety practice, are organized annually. Each student is provided with a PC, a desk and a telephone. They can apply to access all the required laboratories for their research. OU-based training has been offered both face-to-face and online since 2017, thereby enabling part-time and disabled students the same access to and participation in training as their full-time, on-site colleagues.

All B12 postgraduates have access to the Graduate School Network, which includes a Training Zone. Students are required to complete a Skills Audit and Development Plan, which should be maintained throughout the course of their studies. First-year postgraduates are required to write a report on their research progress, attend a mini-viva and pass their probation. Students in some subject areas, e.g. materials engineering, are encouraged to submit their literature review to a scientific journal for publication independently, i.e. without supervisors as co-authors. An example is demonstrated in this link. The students are encouraged to present their new findings to national and international workshops and conferences. Schools provide funds for travel and registration. The awards received by our students include Mamun's 'best student author award ' and Madhavi's James Watt Medal. Both Schools (E&I and LHCS) support their postgraduate students with a successful programme of promoting high quality research, employability and enrichment. This includes an Annual Research Day, a Three Minute Thesis presentation event, and monthly Research Seminars. The Three Minute Thesis presentations are held as part of School's annual away day. Students are invited to present their research to an audience comprised of all academic staff in the School. Students are encouraged to apply for various tutorial positions for OU undergraduate modules, which contributes to the development of their employability.

A dedicated hardship fund and other financial and pastoral support are available through the Graduate School, and all students are entitled to full sickness, disability and parental leave.

Additional needs, such as support for disabilities, are fully provided by, and accessed through, the Graduate School.

h. Covid-19 effects and mitigations

The University responded rapidly to the ongoing and rapidly changing situation during the pandemic and has taken a cautious and targeted approach to returning to campus throughout. The Faculty Pandemic Recovery Group supported business-critical and time-sensitive field and lab work that was possible to achieve within the Government rules and guidelines. When a phased return to campus was allowed, the technical support staff have worked hard to mitigate the impact of a disabling slow-down in data collection and training. Many of the unit lab facilities have been upgraded to allow researchers to access instruments remotely, facilitated by the on-campus technicians. Lab-based training has been facilitated as much as possible within the bounds of what is practically available and possible.

Additionally, the Schools allowed researchers to collect materials such as samples, microscopes and other equipment from campus to facilitate research progress from home. This is in addition to whatever portable IT and office equipment they required to continue their work from home, including laptops, extra screens, headsets, desks and office chairs. Those who had caring responsibilities took advantage of the OU's pandemic-related contingency leave on full pay.

3. Income, infrastructure and facilities

a. Income

The OU B12 members have secured £3.5 million in research grants from external organizations. 41% of our funding is from the EPSRC. The 24 EPSRC grants are held by 9 different staff. 26% of funding is from other organizations including Innovate UK/TSB, RAEng, Royal Society, European Commission, BBSRC, Research England, British Council, RCUK and UKIERI. Other grants are from 21 industrial companies and charities. The largest industrial funder is EDF (19%). There was a steady decline in external research income from 13/14 to 17/18, reflecting both an increasingly competitive landscape for external research funding and the institutional impact of the changes to the higher education funding regime in England. However, our research income profile has shown signs of a healthy recovery within last two years. Research income in 19/20 has doubled from that in 17/18.

b. Infrastructure

The STEM Faculty has completed 69 infrastructure projects, spent over £3.8m and refurbished 4740 m^2 of spaces over the REF period. The laboratories budget averages £800k/year and covers equipment maintenance, basic consumables, gases, small equipment purchases under £50k, and health and safety expenses. In addition, the capital equipment budget, for items costing over £50k, was £300k/year. 17 projects are directly related to B12 staff with a cost of £914k and refurbishment of 964 m^2 of laboratory spaces. The Electron Microscopy Suite has been improved to provide better microstructural characterization facilities and technical support. Two laboratories were re-purposed and upgraded to accommodate new research and post-graduate students intake. Six laboratories were reorganized or upgraded for new machines and new functionalities. £535k has been spent on OpenSTEM Labs which were created in 2015 through a capital investment grant from the then Higher Education Funding Council for England. The OpenSTEM Labs challenge the traditional STEM pedagogical model of students and teachers being co-located in a lab during 'office hours'. We connect students to instrumentation, data and equipment for practical enquiries over the internet, where time and distance is no longer a barrier – any time, any place access. The OpenEngineering Laboratory was launched in 2017 to provide practical lab-based teaching at a distance encompassing engineering, electronics, control, materials, and robotics. In the Covid-19 pandemic, the OpenEngineering Laboratory provided remote access to hundreds of experiments.

c. Facilities

We have set up several new laboratories during the current REF period. **Moncaster** and **Lockett** in collaboration with two other members returned to UOA D32, set up the Open Design Prototype Laboratory, which provides high powered network PC, LCA software and database.

Forsey established several unique facilities in Digital Image Correlation (DIC) Laboratory including the 3D DIC creep rigs that allow long term 3D DIC monitoring of creep and the vacuum retort on the Zwick machine. Qin set up the Electropulsing Laboratory to allow the electromagnetic field treatment of solid and liquid materials at various temperature.

B12 members have free access to Scanning Electron Microscopes (Zeiss Supra 55VP FEG SEM, FEI Quanta 200 3D FIB-SEM, Phenom XL Desktop SEM), Transmission Electron Microscopes (JEM 2100, JEM 1400, JEM 1010), Electron Probe Micro-analyser (Cameca SX100), and the sample preparation and treatment facilities including the workshop. The OpenSTEM Lab assets include 7 analytical chemistry tools, 2 state-of-the-art scanning electron microscopes, 2 optical microscopes, 1 cloud chamber, 1 flow-chemistry reactor and 2 digital particle cameras allowing real-time display of ionizing radiation for remote access. In the current REF period, new facilities were purchased. The table below lists some items over £30k purchased in the REF period. The total cost is around £1.8m. The University has a parallel computing facility with more than 750 CPU's and 2.8TB of RAM that is used exclusively to support STEM research.

Item	Price (£)
Fanuc Robocut	120,006
High Temperature Retort System	80,019
Mass spectrometer agilent 8800 icp ms	180,764
Laser ablation system excite frame	100,014
Portable X-ray residual stress analyser	47,579
EDM 1000 Machine	184,800
Connex 3D printer	99,888
Two Benchtop Scanning EM Phenom XL	186,187
Flow chemistry Vapour Tec Capour Tec R- Series	75,313
Agilent 7890B CN16033042	60,121
NMR SYSTEM bruker avhd400	304,920
Cellnsight CX5 Plate Reader	77,116
Nanoflex zeta charge and size system	50,000
Dual Platform Walter+bai Tensile Test Machine	84,000
X-ray photoemission spectrometer	72,018
Elemental Analyser	30,000
Optical tube assembly	45,300
Total	£1,798k

d Consultancies and Professional Services

B12 members have generated consultancy income of nearly £1m in the current REF period. This includes professional services, providing technical guidance and carrying out experimental measurements for 24 industrial companies and 4 higher educational institutes via 64 consultancy projects.

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

a. Collaborations

Collaboration with colleagues and external partners enables acquisition of complementary knowledge and skills for specific projects. B12's research across all themes is collaborative and multidisciplinary. This is illustrated in our research outputs: 92% of our REF outputs have at least one co-author from external institutes, among which 42% have international collaboration (15 foreign countries). Substantial collaborative research activities are with the European Union (15%), Australia (8%) and USA (8%). Other overseas collaborators are from China, India, Singapore and 6 other countries. The 59 returned REF outputs reveal 67 external collaborative institutes. The institute with which we have collaborated most is University of Cambridge (15%), followed by University of Liverpool (12%) and University of Manchester (10%). Other institutes in excess of 5% include London South Bank University, University of Warwick, Australian Science and Technology Organization, Cardiff University, Coventry University, Imperial College London, SFTC Rutherford Appleton Laboratory and Nanyang Technological University.

Research collaboration within the Open University

B12 members are based at 2 different schools. Each School has staff to returned to different REF units. This conveniences research collaboration and promotes intellectual exchange. Interdisciplinary research in our organization is supported through two pathways, one driven by academics exploring the boundaries of their own discipline, the second through targeted bidding to specific funding opportunities. Each School funds studentships annually and requests staff to form a collaborative supervision team to compete for the studentships. The Faculty funds one B12 studentship annually to allow B12 members across schools to co-supervise the research students on a competitive basis. The Open University Pro Vice-Chancellor's Research and Enterprise Office runs two types of calls: 1. Engagement funding to support the development of partnerships by bringing consortia members together for networking and bid development activity or to support impact acceleration activity that maximises the benefits; 2. Pump priming for facilitating internal / external collaboration and to develop interdisciplinary collaborative research projects. The faculty has equipment funds for each REF UOA to bid for, managed by the Faculty, so that all staff can have access to the facilities. B12 members have built up extensive internal collaborations with staff within and across REF units in the same school and across schools.

External Research Collaboration

OU B12 members were supported to carry out collaborative research with external partners in several ways, including providing matched funding for staff, studentships and equipment, and keeping staff informed of, and encouraging them to attend, networking opportunities and funding workshops. B12 unit has been provided with funds for members to develop external research collaborations by organizing networking workshops, covering travel costs to discuss collaborative proposals and carry out collaborative research, and publicizing collaborative research results. Most of our research projects are in collaboration with other organizations. Examples including **Bouchard's** EPSRC grant (EP/R026076/1) in collaboration with Oxford and Bristol universities. **Moat's** EPSRC grants (EP/T016728/1) in collaboration with University of Manchester. **Nuttall** is involved in EPSRC project (EP/P013600/1) with Sheffield, Lancaster, Diamond Light Source, Imperial, Leeds, Strathclyde, Queen Mary and Surrey. **Qin** is involved in EPSRC project (EP/R029598/1) in collaboration with UCL, Cardiff, Edinburgh, Daresbury and Cranfield.

Industrial collaboration

B12 members have established collaborative relationships with many companies in the UK and abroad. The OU encourages engaged research, which is a descriptor for the different ways that a researcher may interact with stakeholders at all stages of a research project. Engaged research focusses on interplay between academic knowledge and forms of knowledge or practice held within non-academic communities including industrial partners. B12 members have developed scientific partnership in collaboration with 33 companies including Rolls Royce, TWI, Unilever, TATA Steel Europe, Airbus, Lucideon, MPI etc. For example, **Bouchard** is Director of EDF Energy's High Temperature Centre at the OU. We are exploring new opportunities for strengthening collaborations, for example **Collinson** and **Forsey** are working with the V&A Museum which is a non-traditional industry for B12 researchers. The Faculty's external advisory panel contains people from UK and EU industry. 78% of FTSE 100 companies sponsored their staff to take an OU course to upgrade their skills in 2017/18.

Research visitors

B12 members have hosted visitors from the UK and abroad for research collaboration and training purposes. According to our registered records, 19 B12 members from E&I have hosted 51 visitors with official status of Visiting Prof/Academic status in the recent 3 years. Many of them stayed for more than 6 months strengthening our international research collaborations and delivering high quality collaborative research outputs.

b. Contribution to the research, community and society

Advisory Roles

B12 staff act in advisory roles for society and organizations. **Nuttall** chaired the Nuclear Technology Trajectory Review for the UK Government's Chief Scientific Adviser, Sir Mark Walport, from June to December 2016. **Bruce** and **Collinson** are consultants for Epigeum online training course for PhD supervisors. Posma is a consultant for Cambridge Display Technology Ltd and associate consultant at the Oxford Scientific Consultants Ltd. **Moncaster** has been an Associate of Cambridge Architectural Research since 2012. **Heeley** has been appointed to the 'XMaS Expert Focus Group' for the Xmas beamline at the European Synchrotron Radiation Facility' ESRF advising on soft condensed matter user group needs for the ESRF upgrade. **Qin** is on the Royal Society Newton Advanced Fellowships Panel (Physical) between 01/2020 and 12/2022. A number of staff are members of the College of the Engineering and Physical Sciences Research Council. **Neighbour** is the long-standing Chair of EDF Energy's Independent Graphite Validation Group which advises the Chief Graphite Engineer on the operation of the civil nuclear reactor fleet. **Moncaster** is leading a team working for a number of the National Green Building Councils. **Psoma** was an invited external reviewer for the national research proposals of ANR - The French National Research Agency (France) in the field of Biosensors.

Contribution to Science and Engineering

B12 members hold 6 Senior Fellowships from the Higher Education Academy and 6 Fellowships from the Institute of Materials, Minerals and Mining, Institute of Physics, Royal Society of Arts and Royal Society of Chemistry. Staff membership of other UK professional organizations include Institution of Chemical Engineers, Institution of Engineering and Technology, Institution of Civil Engineers, Chartered Institution of Wastes Management, Royal Aeronautical Society, Royal Microscopical Society and The Women's Engineering Society, and also overseas professional institutes including American Society of Mechanical Engineers, American Society for Testing and Materials, Canadian Medical and Biological Engineering Society, European Society of Biomechanics and European Microscopy Society. Collinson is on the committee of the Mid-Anglia Local Section and on the Eastern Region Steering Group of the Royal Society of Chemistry. **Lockett** is an active member of the Structures and Materials Committee of the Royal Aeronautical Society. **Krishnamurthy** is the vice president of Indian chamber of Youth Entrepreneurs. **Gungor** is the chairman of British Society for Strain Measurement.

Editorial roles of scientific journals include: **Collinson** served as an Associate Editor for the Journal of Chemistry (2012-2017). **Neighbour** is a Senior Editor of Carbon. **Bowen** is on the editorial board for Heliyon and MDPI Polymers. **Psoma** is a member of the Editorial Advisory Board of the Open Access Books ToolKit organised by DOAB/OAPEN and Springer Nature Publishing. **Heeley** is on the editorial board of The Journal of Engineering. **Moat** and **Qin** are both on the Editorial Board of Materials Science and Technology. **Qin** is also on the Editorial Board of Scientific Reports and Bulletin of Magnitogorsk State Technical University.

Our B12 members delivered over 40 plenary and keynote presentations during the REF period. Examples include **Nuttall's** Clerk-Maxwell Prestige Lecturer at Institution of Engineering and Technology in Royal Institution in 2015 https://www.youtube.com/watch?v=wCviKi5aD-I&t=157s, **Collinson's** Plenary lecture on recycling post-consumer waste plastics at Sustainable Functional Materials 2018, and **Psoma's** plenary lecture entitled current research trends and applications of biosensors at Bratislava / Slovakia in 2019. 11 staff have organized over 20 symposiums, workshops and participated in organizing committees in some major international scientific events. **Qin** has been in the Executive Scientific Committee of THERMEC during the REF period, an event that attracted over 1000 presentations in 2016, 2018 and 2020.

B12 members have external visiting positions at national and international universities. **Nuttall** has 3 roles at University of Cambridge and is a fellow of the Payne Institute of Public Policy, Colorado School of Mines, USA. **Moncaster** has been a visiting academic fellow at the Department of Engineering at University of Cambridge since 2017 and was an academic champion for the Royal Academy of Engineering Visiting Professor in Transforming Engineering

Culture. **Psoma** was an invited Visiting Professor at Swiss Federal Institute of Technology Lausanne (EPFL), School of Engineering, Institute of MicroEngineering between 2011 and 2016. **Qin** is a guest professor of Chongqing University at China. **Neighbour** is a visiting professor at Birmingham City University.

Contributions to Society

Our research strategy enables B12 staff to actively engage with society at all levels, **Lockett** was interviewed for "Coronavirus: Your Stories" on BBC World News (6/8/20). **Nuttall** discussed nuclear energy policy and the gas helium on BBC Radio Five Live "Wake Up To Money" (27/5/20). **Forsey** was academic consultant for "The secret story of stuff: materials in the modern age", OU/BBC4 co-production proposing themes, guiding the narrative, and checking the scientific content. The show was a critical success attracting ~0.5M viewers for its original broadcast leading to further consultancy on "How to Make". Similarly, **Collinson** contributed as academic consultant on BBC Radio 4 'Inside Science' (2014-17).

B12 members (**Bruce, Collinson, Forsey, Moncaster, Power**) actively contribute to the OpenLearn free learning platform, delivered by The OU as part of its Royal Charter commitment to support the wellbeing of the community. This work also supports the above collaborations with the BBC programmes. Articles also act to inform on current issues and research such as 'How gender equality can fix the construction industry' (**Moncaster**). B12 staff also contribute to other outreach activities such as 'The Conversation' (**Bruce, Moncaster, Nuttall**) to better engage the public. B12 PhD students have presented at MK Soap Box Science for promoting women in science and their achievements.

Awards and Prizes

The academic leadership of our staff has been recognised through the awards and prizes they have won over the REF period. **Nuttall** delivered Clerk-Maxwell Prestige Lecturer for the Institution of Engineering and Technology in 2015. **Krishnamurthy** was an award winner from British Council and Confederation of Indian Industry in 2016 for his novel industrial waste-water treatment method. **Qin's** PhD student Omoigiade received a Silver Medal award from the MRS Fall meeting at Boston, USA in 2016. **Qin** received IAAM Medal award from the International Association of Advanced Materials in 2019 for notable and professional achievements made through work done during the ten years preceding from the year of award. **Nuttall** and his PhD student won the 2020 James Watt Medal from Institution of Civil Engineers Publishing for the paper entitled "Coal in the twenty-first century: a climate of change and uncertainty". **Bouchard's** student Mamun received the 2015 'best student author award' in the PhD student category of the ASME Pressure Vessels and Piping conference. student Mamun received the 2015 'best student author award' in the PhD student category of the ASME Pressure Vessels and Piping conference.