Institution: Keele University

Unit of Assessment: 12 – Engineering

1. Unit context and structure, research and impact strategy

Unit Context

Keele is a research-led campus-based university comprising approximately 2000 staff members and a student population of 11.3k. The broad research base at Keele spans three Faculties: Medicine and Health Sciences, Natural Sciences, and Humanities and Social Sciences. Within each of Keele's three Faculties sits a range of research-led academic Schools. In REF 2014, 97% of Keele's research was classed as world leading, or of international importance.

The engineering unit of assessment (UoA) at Keele brings together engineering-focused staff from the School of Pharmacy and Bioengineering (SPaB) in the Faculty of Medicine and Health Sciences and the School of Chemical and Physical Sciences (SCPS) in the Faculty of Natural Sciences. Both are new Schools formed in response to REF 2014 to enhance the strategic focus on research. SPaB was formed in 2019 through a merger of the Research Institute for Science and Technology in Medicine (ISTM, Director - Prof Nick Forsyth, now Faculty Dean of Research) and the School of Pharmacy (Head of School - Dr Katie Maddock) to combine research and teaching excellence in one hub. The School of Chemical and Physical Sciences (SCPS) was established in 2016 following a restructure of the School of Physical and Geographical Sciences and the appointment of a new research-focused Head of School (Prof Michael Watkinson). Both Schools inculcate the culture of interdisciplinary research that fits with Keele's general research ethos, aligning to the Keele Research Strategy, and supported by the two School Research Directors, Profs Neil Telling and Raphael Hirschi. This is evidenced by the two Schools contributing not only to UoA12 (34.9 FTEs), but also a further 28 FTEs to UoA3: Allied Health Professions, Dentistry, Nursing and Pharmacy, UoA5 Biological Sciences, and UoA9 Physics. This submission to UoA12 follows on from the B15 General Engineering submissions of RAE 2008 (26/52 (sector rank by GPA)) and REF 2014 (20/62 (sector rank by GPA)).

Keele Research Strategy recognises that key research themes are central to the University's ethos and mission and has established cross-faculty interdisciplinary research institutes focussed on Global Health, Social Inclusion, and Sustainable Futures. Engineering underpins two of these Institutes, the Institute for Global Health and the Institute for Sustainable Futures and is a key driver of the impact-focussed research within the Medicine and Health Science and Natural Sciences faculties, as well as large scale campus projects. Two of these projects are the Smart Energy Network Demonstrator (SEND) and the hydrogen energy project HyDeploy evaluating the UK's first hydrogen/natural gas blend for domestic use. These projects have attracted over £23.5 million in funding and exploit Keele's unique privately owned and operated utility network to provide a laboratory where new low-carbon technologies and interventions can be researched, developed and tested in a real-world environment.

Strength in Engineering research at Keele is reflected in overlapping areas forming three broad and complementary overarching research strands: **Bioengineering, Healthcare Technologies and Materials**. Combining the expertise and facilities of the two Schools (SPaB and SCPS) has delivered the critical mass required for a vibrant multi-disciplinary Engineering research environment. The two Schools support these strands via their internal research groupings. SPaB organises its engineering research into groups which include: Materials for Biomedicine (feeding into Bioengineering and Materials), Cancer and Cardio-Respiratory, Neural Biology and Neural Repair, Regenerative Medicine and Orthopaedics and Biomechanics (all feeding into Bioengineering and Healthcare Technologies). Researchers in SCPS span a broad range of disciplines, including many previously returned in the REF2014 General Engineering submission. Engineering focussed research at SCPS is organised into three themes: Materials Science and Renewable Energy, Synthetic Chemistry (both feeding into Materials) and Forensic and Analytical Science (feeding into Healthcare Technologies). Combining the research strength of both Schools provides a foundation for a diverse Engineering portfolio, which includes

biomaterials, medical device engineering, tissue engineering, nanomaterials, nanotechnology, sensors and actuators, and smart energy materials.

The quality of Engineering research and expertise has resulted in Institute of Physics and Engineering in Medicine accreditation (from 2016 onwards) of our MSc Biomedical Engineering, as well as enabling the expansion of postgraduate and undergraduate taught courses, including, for example, industry-affiliated MSc Medical Engineering Design, MSc Analytical Sciences for Industry, and a new BSc Cell and Tissue Engineering (first intake October 2021).

In this submission, UoA 12 includes 37 category A staff (34.9 FTE). Maintaining the critical mass of REF2014, we have balanced the natural turnover of staff with strategic recruitment to key areas in Engineering, including the recruitment of ECRs (30% as reflected in the HESA return), thereby consolidating our research base and enabling future growth.

Our core objective from REF2014 was ***to foster an interdisciplinary research environment*****,** which we have achieved by consolidating critical mass to maintain areas of strength whilst growing research in strategically aligned cognate areas (**Bioengineering, Healthcare Technologies and Materials**).

Unit Structure

Bioengineering focuses on the development of enabling technologies in cell and tissue engineering and applied clinical research in regenerative medicine and rehabilitation. The development and study of cellular phenomena and materials in clinical applications, such as autologous cell therapy treatments and surgical repair, is a major focus of this theme, underpinned by multidisciplinarity, including engineering, modelling, and fundamental biology. Our research extends across the body, including bone, cartilage, eye, heart and spinal cord; and ranges from fundamental mechanistic research to translational research, leading to approval by the National Institute for Health and Care Excellence of a cell therapy to treat patients with cartilage defects. Our research employs a wide range of engineering approaches including biomaterials, cell and tissue engineering, engineering biology, engineering design and modelling and simulation. The bioengineering strand links closely with, and has significant support from, our other two strands (Healthcare Technologies and Materials), with a long-term strategy of having materials chemistry fundamentally underpinning this strand.

Selected grant awards within this strand during the census period include:

- EPSRC & MRC CDT in Regenerative Medicine (together with Loughborough and Nottingham), £5.6M (FEC, full award), 2014 onwards
- EU FP7 Biodesign, ref: 262948, €11M, (full award), 2012-2016
- EU H2020 FET-Open Magneuron, ref: 686841, €3.5M (full award), 2016
- EU H2020 ITN P4 FIT, ref: 955685, €4M (full award), 2020
- MRC Experimental Medicine Challenge Molecular & Cellular Medicine Board, ref: MR/N02706X/1**,** £607k (FEC), 2016-2019
- MRC Regenerative Medicine Research, ref: MR/S015167/1, £429k (FEC), 2019 onwards
- Versus Arthritis Tissue Engineering & Regenerative Therapies Centre (together with Aberdeen, Cambridge, Newcastle and York), ref: 21156, £2M (full award), 2016

Appointments in this REF period to strengthen this strand include **Dr Chris Adams, Dr Melissa Bowerman, Dr David Cabrera, Dr James Everett, Dr Stuart Jenkins, Prof Peter Ogrodnik, Dr Karina Wright** and *Dr Nicholas Wragg (staff members whose FTE contributes to this UoA are indicated in bold and alternate UoAs by asterisk).

Healthcare Technologies describes research of medical devices, nanotechnology, and diagnostic engineering, with complexity covering length scales from macroscopic engineered solutions to treat limb fractures, to cellular level spectroscopy and imaging, as well as applications of biomedical nanotechnology. For example, work on assistive technologies includes computational modelling and the development of medical devices to improve fracture

management. Research focused on spectroscopy and imaging includes mass spectrometry studies of biomarkers for disease, advanced x-ray spectromicroscopy studies of pathological structures in brain tissue, and the development of a new magneto-optical microscope for life science studies (the first of its kind). Further to this, work in the strand has explored the design and use of nanotechnology for drug, gene and cell targeting, as well as magnetic nanoparticle hyperthermia for applications in cancer treatment and stroke.

Selected grant awards within this strand during the census period include:
- EPSRC Responsive Mode, ref: EP/N033140/1, £422k, 2017-2019
- EPSRC Standard Research Grant, ref: EP/P011403/1, £533k (FEC), 2017-2020
- EU FP7 ITN Mag(net)icfun, ref: PITN-GA-2011-290248**,** €4.4M (full award), 2014
- EU H2020 ERC TransPhorm, ref: 683108**,** €2.4M (full award), 2016
- European Space Agency ARTES 20 Demonstration Projects (ARTES IAP: Integrated Applications Promotion (IAP) Programme- Feasibility), ref: 18082017, £212k, 2017-2019
- Wellcome Trust, Sir Henry Wellcome Postdoctoral Fellowship, ref: 218671/Z/19/Z, £300k, 2020

Appointments in this REF period to strengthen this strand include **Dr David Cabrera**, *Dr Pooya Davoodi, **Dr James Everett, Prof Peter Ogrodnik** and *Dr Abigail Rutter.

Materials, a key research theme within the Engineering focus of SPaB and SPCS, seeks to develop, characterise and apply innovative new materials to help solve a range of global problems. These have included the development of functional meso and nanoscale materials with applications in catalysis, green chemistry, biomedicine and sensing applications, including collaboration with industry (both local SMEs and multinationals). In addition, and as a result of more recent appointments, activity has developed in the synthesis and modelling of novel 2D materials for a range of applications as well as energy storage materials. Ongoing and developing lines of research include a range of sensing and analytical approaches to the development of new systems for applications in medical devices and agricultural sensing, as well as improved biomaterials and the analysis of biominerals using a range of novel techniques, including advanced x-ray characterisation.

Selected grant awards within this strand during the census period include:
- EU FP7 TANGO, ref: 316654**,** €3.7M (full award)**,** 2012-2016
- EPSRC Standard Research Grant, ref: EP/P000762/1, £313k (FEC), 2016-2019
- EU H2020 ITN POLKA, ref:813367, €4M (full award), 2019
- EPSRC Standard Research Grant, ref: EP/T0073971/1, £430k (FEC), 2020-2023
- MRC UKRI Future Leaders Fellowships**,** ref: MR/T019522/1, £1.2M (FEC), 2020-2024
- NERC NSF/NERC Signals in the Soil, ref: NE/T012331/1, £1.3M (FEC, full award), 2020-2023
- Nista Diagnostics Inc, £1.1M (full award), 2020

Appointments in this REF period to strengthen this strand include: **Dr Nilanthy Balakrishnan, Dr David Cabrera**, *Dr Pooya Davoodi, **Dr Charlene Greenwood, Dr Chris Hawes, Dr Peter Matthews, Dr Gavin Miller, Dr Juliana Morbec** and **Prof Michael Watkinson**.

Research and Impact Strategy

The vision for Engineering research at Keele University is to develop research which aims to address key global challenges, underpinned by a commitment to maintain an internationally competitive infrastructure, in support of research-focussed academics. To deliver upon this vision we have identified a number of strategic aims spanning three key integrated components:

- ***We aim to maintain a balance between experienced and early career researchers across our UoA*****,** recognising that growth per se is not a default pathway to institutional research success. A carefully constructed critical mass of researchers is fundamental in creating an environment conducive to research. Recruitment will be tailored around areas of research strength, ensuring stability within established expertise where required, whilst maintaining flexibility to pivot towards areas of need in response to external drivers.

- Focus of activity across a limited range of broad, fundamental, research topics is essential in creating a collaborative and supportive environment. ***We aim to maintain our activity levels across established areas of excellence (e.g., Bioengineering and our international exemplars in cell therapy) while establishing growth in Interdisciplinary Materials research*** (drawing on emergent bio-, renewable, and smart materials expertise through strategic recruitment aligned with institutional priorities and strengths (see above).
- World-leading research requires excellent underpinning facilities. ***We will aim to retain an international edge in our equipment-based infrastructure through our ongoing policy of strategic replacement and acquisition.*** The current REF cycle has witnessed substantial investment, averaging £10m per annum, ensuring provision of a competitive research environment. We recognise this as an ongoing pursuit and will seek both internal and external funding support, to provide key equipment and start up packages to ECRs and continue to secure substantive access to national and international facilities.

Recognising the value and necessity of embedded impact facilitation, Keele established the Directorate of Research, Innovation and Engagement (RIE) to support and manage research achievements and to maximise their societal potential. RIE developed new initiatives such as the annual (competitive) Impact Acceleration Fund and the annual Celebrating Impact Conference, to ensure that exploiting the impact of our research remains firmly embedded within our research community mindset. The Impact Accelerator Fund helps identify and align research priorities to prospective impact by tracking key academic outputs and providing strategies for the identification, gathering, synthesis and linkage of evidence from this research to potential stakeholders.

At submitting UoA level, specific impact is identified and nurtured through annual staff appraisal processes and then supported by our School Directors of Research network. The UoA has integrated the Keele Impact Acceleration Fund in these processes, thus providing financial support for the development of impact by providing resources to prototype, engage industry and maximise public awareness. This strategy has helped us to develop specific impacts that form part of the impact case studies submitted in the current REF. Examples are the web app associated with the "Advancing regenerative medicine: from bench to NICE-approved treatment for early osteoarthritis" case study, and support for a data-gathering exercise as part of our "Implementation of advances in fracture management leading to research led support for healthcare and the medical devices industry" case study. At least as important, our strategy has also identified ongoing research whose impacts will be developed and will be part of future case studies.

A key aspect of delivering impact from our research is the direct involvement it affords with clinicians and patients, allowing translational impact to grow more rapidly than is typical in engineering environments. In addition, direct business engagement is promoted by Keele's Research Innovation and Support Programme (KRISP) and Business Bridge which present business and industry-led challenges to Keele staff, providing new opportunities for impact development while simultaneously creating a sustainable route for further growth. This led to collaborative work between members of the UoA and industry, opening an important route to future impacts.

Integrity and Open Science

Aligned with the principles of the Concordat for Research Integrity, all staff in this UoA are encouraged to share examples of best practice, to openly discuss methods, transparency and reproducibility, and raise concerns of malpractice. To support this endeavour, Keele has established a network of Research Integrity Champions who help to nurture the culture of research integrity and good research practice at UoA level. Further, Keele has an Academic Lead for Research Integrity and Improvement who is also the main contact for the UK Reproducibility Network. The Academic Lead for Research Integrity and Improvement leads Keele's network of research integrity champions and works closely with the Project Assurance Research Integrity team to deliver the University's research integrity and reproducibility strategy.

Keele has an implemented quality management system (QMS) for the main areas of research that are governed by legislation, for example, health and social care research, human tissue research or animals in scientific procedures. The QMS for each of these areas includes (1) documentation - policies, standard operating procedures, working instructions and quality-controlled documents (2) training - for health and social care research the Project Assurance Research Integrity team manage a training programme to support users of the QMS and (3) processes and mechanisms by which the University maintains oversight of the research activities, either through audit, oversight committees or research misconduct investigations.

This UoA is at the forefront of developing an open research environment; research outputs (all types) are made openly available which began in advance of the current REF policy and is reflected in its high proportion of open access compliance for REF 2021. This UoA works with partners to seek external funding for open research, has been heavily involved in developing and implementing a research data policy for the University, and was an early adopter of the Keele data repository, enabling datasets to be openly available for others to re-use, as evidenced by this example: http://eprints.keele.ac.uk/3701/.

2. People

Each of the submitting UoA's three research strands is centred around key and associated staff across the assessment period. Underpinned by its People Strategy, Keele strongly fosters a culture of staff development within the organisation and recognises that institutional movement can be an essential component of an individual's career progression. Staff members whose FTE contributes to this UoA are indicated via underline and alternate UoAs by asterisk.

Bioengineering: Dr Chris Adams, Dr Melissa Bowerman, Dr David Cabrera, Prof Divya Chari, Dr Tina Dale, Dr James Everett, Prof Nick Forsyth, Dr Vinoj George, *Dr Alan Harper, Dr Stuart Jenkins, Dr Oksana Kehoe, Dr Jan Herman Kuiper, Dr Helen McCarthy, Prof Peter Ogrodnik, Prof Sally Roberts, Dr Mark Skidmore, Dr Caroline Stewart, Prof Neil Telling, *Dr Nicholas Wragg, Dr Karina Wright, *Dr Pensee Wu, Prof Ying Yang

Healthcare Technologies: *Prof Peter Andras, Dr David Cabrera,*Dr Anthony Curtis, *Dr Pooya Davoodi, Dr James Everett,*Dr Martin Frisher, Dr Heidi Fuller, *Dr Monte Gates, *Dr Alan Harper, Dr Sarah Hart, Dr Jan Herman Kuiper, *Dr Wen-Wu Li, *Dr David Morgan, *Dr Gary Moss, *Dr David Mottershead, Prof Peter Ogrodnik, *Dr Abigail Rutter, Dr Mark Skidmore, Dr Caroline Stewart, *Prof Josep Sulé-Suso, Prof Neil Telling, *Dr Szu-Shen Wong.

Materials: Dr Nilanthy Balakrishnan, Dr David Cabrera, Dr Richard Darton, *Dr Pooya Davoodi, *Dr Falko Drijfhout, Dr Charlene Greenwood, Dr Chris Hawes, Professor Maria Heckl, Dr Martin Hollamby, Dr Robert Jackson, *Dr Graeme Jones, Dr Peter Matthews, Dr Gavin Miller, Dr Juliana Morbec, Dr Matthew O'Brien, Prof Mark Ormerod, Dr Aleksandar Radu, Prof Neil Telling, Dr David Thompson, Prof Michael Watkinson, Prof Ying Yang, Dr Vladimir Zholobenko.

Keele values its staff, as reflected in our university being ranked 31st of 766 universities from 85 countries (6th among European universities) measured on the University Impact Rankings in the area of good health and well-being, which measures, amongst other categories, the health of staff and students (https://www.timeshighereducation.com/rankings/impact/2020/good-health-and-well-being). Achieving this high ranking relied on high-quality staffing strategies and staff development policies that have been implemented institute-wide, with adherence to the policies by individual UoA's monitored regularly. The quality of the submitting UoA's own staff development strategy is reflected in the three bronze Athena SWAN awards earned by the two Schools (The School of Pharmacy and Bioengineering (SPaB) and the School of Chemical and Physical Sciences (SCPS)) and the former Research Institute of Science Technology in Medicine (ISTM) that make up the UoA.

The UoA's staffing strategy and staff development policies build upon the university-wide policy and strategy. Excellence in research is an essential criterion for all new appointments to the UoA,

and appointments are made to ensure improved strength in our key research strands and alignment with our major research questions. To achieve our main strategic objective of ***maintaining and fostering an interdisciplinary research environment***, we particularly appoint staff whose research profile demonstrates an openness to interdisciplinary research and has the potential to generate impacts beyond academia. We have also balanced turnover of staff with the appointment of new academics at a variety of levels, for example *Davoodi, George, Jenkins, *Mottershead, *Rutter, *Wong and Wright as new Lecturers, Cabrera (Wellcome Trust Research Fellow), Dale and Everett as Research Associates with research independence and Ogrodnik as a Senior Lecturer in SPaB, and Balakrishnan, Greenwood, Hawes, Miller, Morbec as new lecturers, Matthews as a Research Fellow, and Watkinson as Head of School in SCPS. Three examples of such appointees are Dr Karina Wright, a bioengineer working towards delivering clinical outcomes, Dr David Cabrera, whose research interfaces physics and bioengineering and Dr Charlene Greenwood who works at the interface of biomaterials and diagnostic medicine. The interdisciplinary work of our ECR appointments in healthcare technology and bioengineering has already contributed to our impact case study on Advancing Regenerative Medicine and is integral in developing further and new impacts on health and the economy.

Early Career Researcher Development

A high-profile successful example of career support and development of ECRs is the award of a UKRI Future Leaders Fellowship to Miller in 2020 (£1.2M) which was supported by the development of a strong culture of mentorship in this UoA. The quality of mentorship is reinforced through our Unconscious Bias training that is mandatory for all mentors and managers. Two further appointees (Cabrera and Wright) are also good examples of our ECR staff development strategy. Both started their research career in our UoA as postgraduate students. Recognising their potential to achieve excellence, they were subsequently recruited as postdoctoral research assistants. All postdoctoral researchers have an annual appraisal, helping to support their development to independent researchers, in line with the expectations from the Concordat to Support the Career Development of Researchers and reflective of our HR Excellence in Research award (renewed 2019). Integrating them into our multi-disciplinary research culture allowed them to start self-directed independent research, culminating in their appointment as Lecturer (Wright) and subsequent promotion to Senior Lecturer, Sir Henry Wellcome Postdoctoral Fellowship (Cabrera), with both included in our submission as Category A staff.

Staff Development and Support

Once appointed, staff are mentored to improve their research profile (e.g. through obtaining grant income or raising their external visibility). Doing so has allowed many of our staff to apply for promotion and has led to the promotion to Senior Lecturer of Darton, Fuller, Hart, Kuiper, *Li, Miller, O'Brien, Radu, Skidmore, Thompson, Wright and *Wu, as well as promotion to Professor of Chari, Forsyth, Telling and Yang during the current REF cycle. However, raising their research profile also allows staff to seek promotion elsewhere, such as Blana and Chadwick (Lecturer and Reader, University of Aberdeen), Hoskins (Reader, University of Strathclyde) and Sharples (Professor, Norwegian School of Sport Sciences).

The UoA recognises the value of strategic secondments and staff exchanges, providing staff with the opportunity to visit international partners through external funding opportunities such as EPSRC, Royal Society and EU (Erasmus+), examples in the current cycle include Chari to Cambridge and El Haj to Oxford through the support of EPSRC discipline hopping awards and exchange visits: Heckl to University of Pisa (Italy) and Forsyth to Tongji (China) through Royal Society support and Radu's British Council funded project to engineer smart sensor technology for application in agriculture in Peru.

The UoA's staffing strategy is embedded within Keele's general policy to ensure staff enjoy flexible, family-friendly working arrangements and annual appraisals (with embedded research plans) to plan, recognise and reward research excellence and identify development or training needs. This includes access to the Academic (Maternity) Returners' Fund to support transition back into the workplace. All new staff have both teaching and research mentors, with research mentors aligned to research themes. Mid - established career researchers with responsibilities in

research and mentorship are invited to join the Research Leaders' Network: a forum for such researchers to be involved in guiding the University's strategic research direction and discussing the University's research environment to ensure compliance with the research Concordat. Research Leadership training and coaching is also made available to these staff.

We promote, encourage and support our academics to develop their careers and esteem indicators (i.e. through a targeted approach to UKRI peer review college membership). We are supportive of staff exchanges and secondments both in academia and industry where these serve to enhance personal profiles, development and reputation. For example, the UoA stimulates exchange and collaborative work between academia and other sectors, such as industry or public sector bodies, by helping staff in applying for funding for these collaborations, promoting them during annual appraisals, providing time for these activities, and recognising them in promotion criteria. This led many of our staff to seek such collaborations, including an Innovate-UK funded collaboration with Wienerberger Ltd, an MRC-funded collaboration with Terumo BCT Europe, provision of courses to industry, and engagement with NICE. Achieving impact from research is similarly promoted by helping staff to identify opportunities for and examples of impact, focusing on impact during appraisals and recognising impact in promotion criteria.

Postgraduate Research

Keele provides a high quality and effective postgraduate research training environment. This is evidenced by the current offers through the EPSRC/MRC Centre for Doctoral Training in Regenerative Medicine and Wellcome Trust PhD Programme for Primary Care Clinicians, amongst others. This UoA has delivered PGR training to 346 Postgraduate Research students through a college of over 29 trained supervisors. PGR training covers all four Vitae training domains including aspects of supervision, resources, research culture, progression, responsibilities, teaching opportunities, research skills, and professional development. These are complemented by the offer of an annual allowance to provide tailored support (e.g., mentorship and coaching, language, communication skills training) to all PGR students. ***The biennial Postgraduate Research Experience Survey (PRES) consistently show Keele PGR student satisfaction to be above benchmark sector performance***. Specifically, in the most recent PRES (response rate 63% compared to 46% nationally), Keele secured an overall satisfaction score of 86%, scored higher than the Sector benchmarks on all areas, supervision (5% above sector benchmark, 3rd place overall), research culture, research skills, and professional development, Further, Keele ranked 10th (overall in PRES 2019) out of 107 UK institutions for the research opportunities offered to postgraduate students.

Research training is embedded across an infrastructure that encompasses state-of-the-art laboratories, NHS partnerships (University Hospital of North Midlands Trust and the Robert Jones and Agnes Hunt Orthopaedic Hospital), Keele University Science Park, our industrial partners and strategic access to regional infrastructure and equipment available elsewhere such as the Liverpool Technology Directorate and Midlands Innovation. ***Together, this demonstrates a commitment to a PGR training strategy that, from induction through to employment, is integrated with external partners to enhance the impact of Keele University research on our region, nation and beyond.***

In line with Keele's PGR Code of Practice, all PGRs are required to develop a training plan. All PGRs are also members of the newly founded Keele Doctoral Academy (KDA), launched in April 2020. The KDA provides a unified platform for PGR support, governance and training, and provides opportunities for PGR students to connect with communities of interdisciplinary researchers across the university. Such work is shared through an annual, university-wide Postgraduate Research Symposium that promotes an ambitious blend of original research and public engagement skills. PGR students take a lead role in organising the Annual Postgraduate Research Symposium, which delivers a showcase of PGR research through a combination of oral presentations, posters, turbo talks and 3-minute thesis competition, with students awarded prizes for scientific quality and dissemination to a lay audience. Students are also encouraged to present their work institutionally, nationally and internationally.

Via the KDA our PGR students receive high quality training encompassing ***detailed personal development and learning plans, and transferable, employability, scientific, and subject-specific skills in accord with the Vitae Researcher Development Framework***. This flexible training package is delivered through laboratory training, formal PGR modules (e.g. Research Ethics, Governance, Health & Safety, Communication) and the KDA itself, and is complemented by courses delivered by external organisations (e.g. relevant Learned Societies, UKRI funding agencies, partners in existing CDT/DTC with Keele or those commissioned by Keele such as Writing point "Science writing for communicating clearly, accurately and effectively"). Research themes within the University are distributed across different laboratories and sites (including clinical sites), encouraging visits and the interchange of ideas. Most seminars are organised at a research theme level, encouraging regular meetings of lab-based members, clinical colleagues and industrial contacts from the Keele University Science Park. Students are also members of the University's Postgraduate Association and Institute for Liberal Arts and Sciences (www.keele.ac.uk/ilas/), ***providing a strong cultural and academic hub that supports the community of postgraduate researchers across all faculties of the University***.

All doctoral supervisors are required to be research-active at the time of supervising doctoral students, undertake formal training and undergo a period of 'probationary' supervision under the guidance of an experienced supervisor. Additional training is available for supervisors around areas such as supporting student mental health.

Equality, Diversity, and Inclusion

Keele University currently holds an Athena SWAN (Scientific Women's Academic Network) Bronze Award and a Race Equality Charter (REC) Bronze Award, is a Disability Confident (DC) Employer and a Stonewall Diversity Champion. In addition, the two schools that make up the Engineering UoA (SCPS and SPaB) separately hold three departmental Athena SWAN Bronze Awards, two of them held by the merged school and institute that form SPaB (the Research Institute for Science and Technology in Medicine and the School of Pharmacy); SCPS also holds JUNO Supporter status. This clearly demonstrates the UoA's commitment to the ten guiding principles of Athena SWAN around addressing gender equality, the five guiding principles of the REC around equality of ethnic minority staff and students, the two DC themes of employing disabled people and the four Stonewall priorities for sexual orientation and gender identity equality, diversity and inclusion. Evidence of how the UoA applies these principles are found throughout our two Schools. For instance, our PDRAs (fixed-term staff) are encouraged to apply for permanent positions that are advertised in our Schools, which has led to four appointments of our fixed-term staff to permanent lectureships in the assessment period (Adams, Fuller, Jenkins and Wright), of which two are female (Fuller and Wright). We also support our female researchers in achieving leadership positions. Examples are one former PDRA (Blana) who is a member of the EPSRC RISE (Recognising Inspirational Scientists and Engineers) cohort and went on to find a lecturing position at Aberdeen, and our yearly support for PDRAs and lecturers to attend the Aurora Leadership Programme. Staff returning from long-term leave, such as parental leave or long-term illness, have a range of options to suit the individual: phased return, flexi-working, compressed hours or full-time reduction to part-time hours if the role is permitting.

3. Income, infrastructure and facilities

Income

Following on from REF2014 the submitting UoA initiated an internal grant crafting panel, complimented by the Keele Peer Review College, for large grant applications, to ensure support to all researchers, irrespective of their career stage, in preparing research proposals with an aim of increasing the overall quality of submissions. As a result, Engineering research at Keele has maintained a successful profile in attracting competitive funding from both national and international sources in an increasingly competitive landscape.

The total grant income over the census period is **£22.9m**, a **19% increase** on REF2014, and includes awards from major funders including UKRI (EPSRC, ERC, MRC, BBSRC and STFC), industry-academic partnership grants (from the TSB and Innovate UK and KTP-Innovate UK),

NIHR, the EU, national and international charities including Wellcome Trust, Versus Arthritis, British Heart Foundation, Royal Society and the Alzheimer's Society) and industrial sponsors, including consultancy arrangements, with large to small/medium enterprises such as AbbVie Ltd, Astra Zeneca, Baker Ruskinn Ltd, Boehringer Ingelheim UK Ltd, Daiichi Sankyo UK Ltd, Johnson Matthey, Keeling & Walker Ltd, LEO Laboratories Ltd, Medtronic Limited, Merck Sharp & Dohme Ltd, Novartis, Novartis Pharmaceuticals UK Ltd, Phagenesis Limited, PneumaCare Limited, Riboscience, Roche Products Ltd, Terumo, TEVA Pharmaceuticals Ltd and Thermal Ceramics UK Ltd.

Two examples of activity drawn from the list above are Darton (KTP Keeling & Walker Ltd) and Wright (Terumo). The collaboration with Terumo gave our UoA the opportunity to install a state-of-the-art GMP-grade automated cell culture platform. This platform was important in our work as part of the MRC/Inovate UK Biomedical Catalyst (BMC), starting as a feasibility study as part of our BMC Confidence in Concept grant and leading to a successful bid in 2020 to the BMC Developmental Pathway Funding Scheme with the aim to produce and trial allogeneic cartilage progenitor cells for clinical use. The KTP with Keeling & Walker led to the development of a series of inorganic materials for the absorption and/or reflection of infrared radiation. These materials are being applied for a range of applications including in agricultural films, security inks and laser marking. The work has helped generate in excess of £500k profit per year for Keeling & Walker Ltd by 2021 as well as fundamentally changing the company's approach to research, defending their niche position in infrared materials and reducing environmental impact. International outsourcing of large-scale manufacture of the materials developed has also occurred.

Key awards which have contributed to this income include:

- EPSRC & MRC CDT in Regenerative Medicine (together with Loughborough and Nottingham) £5.6M (FEC, full award), 2014 onwards
- Versus Arthritis Tissue Engineering & Regenerative Therapies Centre (together with Aberdeen, Cambridge, Newcastle and York), ref: 21156, £2M (full award), 2016
- EU FP7 ITN Mag(net)icfun, ref: PITN-GA-2011-290248**,** €4.4M (full award), 2014
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- EU H2020 ERC TransPhorm, ref: 683108, €2.4M (full award), 2016
- EU H2020 ITN POLKA, ref:813367, €4M (full award), 2019
- EU H2020 ITN P4 FIT, ref:955685, €4M (full award), 2020
- MRC UKRI Future Leaders Fellowships**,** ref: MR/T019522/1, £1.2M (FEC), 2020
- NERC NSF/NERC Signals in the Soil, ref: NE/T012331/1, £1.3M (FEC, full award), 2020
- Nista Diagnostics Inc, £1.1M (full award), 2020

Research funded from the above sources has already led to high-quality research outputs, including Bardsley et al., 2017 (BioDesign), Hulme et al., 2017 (Versus Arthritis Tissue Engineering Centre), Cabrera et al., 2018 (Mag(net)icfun). It has also contributed directly to our impact case studies, including Advancing regenerative medicine (Versus Arthritis).

Infrastructure and facilities

Engineering research is situated across three key locations: the main Keele campus, the Guy Hilton Research Centre (GHRC) at the University Hospital North Midlands (UHNM), and the ARC/Torch building at the Robert Jones and Agnes Hunt Orthopaedic Hospital (RJAH). Following on from REF2014, Keele University has made major investments in the campus facilities that house engineering research. These were largely realised in a £45M campus wide investment delivering a ***new Central Sciences Laboratory (£34M, including £2M of capital investment in equipment)*** opened in 2019, a unique facility that brings together different disciplines, including chemistry, physics, pharmacy and geology. This new facility is complemented by an ongoing refurbishment programme of the ***Lennard-Jones laboratory*** (£7.2M). This has already resulted in the repurposing of former teaching facilities for example a laboratory being converted to a research space with 20 fume hoods. The new ***David Attenborough Laboratories*** (£11M) were opened in 2019, doubling the existing laboratory space available for bioengineering research.

Keele and the UoA are committed to identifying and addressing challenges related to inequality and to ensure equal access to all our facilities and support structures. Taken together the UoA has benefited from an averaged ~£10M investment in research infrastructure and equipment per annum over the REF2021 census period.

Researchers in the UoA have access to facilities commensurate with the needs of our research. Inventory categorisation has allowed a continuous cycle of annual replacement to be implemented, minimising critical failure risk and ensuring that advancements in energy efficiency can be realised as rapidly as possible. On site facilities include access to material production facilities such as vacuum based materials deposition, hydrothermal synthesis, dedicated furnace room, and glove box facility for handling air/moisture sensitive materials, as well as biomaterials production such as 3D printers and nanofibre spinning. These production facilities are supported by a suite of materials characterisation techniques including NMR spectroscopy facilities (equipped for both solution and solid state), XRD facilities for single crystal and powder diffraction work, electron microscopy, Inductively Coupled Plasma Spectrometers (ICPMS), materials testing (electromagnetic (BOSE ElectroForce) and servohydraulic materials testing machines), and a wide range of mass spectrometry equipment including low and high mass resolution analysers, with technical support for instrument maintenance and development. In addition, specialist facilities are available for nanoparticle analysis (e.g., Zetasizers, AC susceptometry), as well as gas and breath analysis (SIFT-MS).

Biological experimentation and characterization equipment include flow cytometry (FACSCANTO II, BD Biosciences), genomic and proteomic analysis (including high-throughput techniques such as gene arrays, PCR and mass spectrometry), and fully equipped cell culture facilities (at each site) including state-of-the-art oxygen control culture workstations. These are complemented by a commercial Bioreactor suite incorporating ElectroForce 3200 (TA Instruments), Instron Ligaten, Rotating Wall Vessel (Synthecon), 2D/3D Stretch (Flexcell international), Quasi vivo perfusion (Kirkstall Ltd), Quantum (Terumo BCT), and Biaxial stretching (CellScale). Research-grade bioreactor systems are developed in house to address specific research questions. Bio-imaging modalities include fully automated long-term life cell tracking microscopy (Cell-IQ), atomic force microscopy (Bioscope Catalyst), confocal microscopy (including an Olympus FV1200), confocal Raman microscopy (Thermofisher DXR2), micro-CT (Scanco), biological electron microscopy (scanning and transmission) and optical coherence tomography. Healthcare related research benefits from direct links with the medical community, in particular, our two hospital-based research centres. The GHRC is a purpose-build research facility, in close proximity to UHNM, entirely aimed at bioengineering research. Opened in 2008, the GHRC gives researchers access to GMP-grade clean rooms, patient assessment rooms, a laser lab with high-spec optical benches and a magnetics lab with a suite of magnetic materials preparation and analysis facilities. RJAH has two dedicated linked research buildings (ARC/Torch) and houses a GMP grade human cell manufacturing facility - currently the only UK-based manufacturer licensed to produce autologous chondrocytes for clinical cell therapy as well as a clinical Vicon gait lab for diagnosing and analysing movement disorders. These clinical links allow the UoA to perform relevant clinical trials, including a nationally funded (MRC and Versus Arthritis) trial of autologous stem cells and chondrocytes to repair cartilage defects, and have directly contributed to the three Impact Case Studies submitted in this UoA.

Researchers within the UoA share facilities with other HEIs and make extensive use of major national and international research facilities. Through our CDT and Tissue Engineering Centre, for example, staff and students access facilities at our collaborators and vice versa. Keele has established a formal partnership with the University of Liverpool's Technology Directorate (TD), enabling Keele researchers to access specialist facilities, associated equipment and expert staff across a range of biomedical science-related areas. So far this has generated £1.9M of income from RCUK (now UKRI), shared with the TD. In 2017 Keele was invited to become a member of Midlands Innovation, a partnership of the 8 most research-intensive universities in the Midlands to power growth in the region. One result of this partnership is Midlands Health Innovation, which combines the 7 partners with medical schools and aims to share mass spectrometry and medical imaging facilities, for example, and facilitate collaborative grant applications. This allowed cross-consortium support for two BBSRC Alert equipment awards with the University of Liverpool

Institute of Integrative Biology (2016 and 2018). Major research facilities used in the census period include the Diamond Light Source (DLS), ISIS neutron source and the European Synchrotron Facility (Grenoble), the ALBA synchrotron facility (Barcelona) and the Advanced Light Source (Berkeley, USA). Our staff are active in managing these facilities, such as Prof Telling (DLS Chair of beamline I08 working group, DLS User Group lead for Imaging and microscopy), Prof Sulé-Suso (DLS user working group soft condensed matter) and Dr Hollamby (ISIS facility access panel). High impact outputs from the use of these facilities include, Datta et al., 2020, Hollamby et al., Nature 2020, and Everett et al., 2018 (featured in a special edition of Themed Collection: Nanoscale Most Popular Articles. EPSRC/Diamond Light Source).

Our collaborations with industry have led to a number of in-kind benefits. These have included access to a clinical-grade bioreactor (Terumo Quantum) to support development of new protocols for manufacturing allogeneic chondrocytes for cell-therapy. In addition, Baker Ruskinn have donated state of the art cell culture technology for stem cell engineering research and The Electrospinning Company provision of bespoke nanofibre mats.

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

Collaborations

Keele and the submitting UoA recognise the importance of local, national and international collaboration with users, stakeholders and academic partners to achieve their research aims and impacts. These collaborations span a wide range, with local single projects and research programmes, national research and training centres and international partnerships, and are the foundation of our grant income.

The UoA has developed strong networks with clinical, industrial and academic collaborators. ***Key clinical collaborators*** are University Hospital of North Midlands (UHNM), one of the largest NHS trusts in the country serving around three million people, and Robert Jones and Agnes Hunt Orthopaedic Hospital (RJAH), one of the UK's five specialist orthopaedic centres serving the whole of the UK. Two exemplars of local clinical collaborations are the UoA's role in improving acute fracture care at UHNM (Ogrodnik) and the provision of regenerative medicine and innovative gait analysis for clinical use at RJAH (Kuiper, McCarthy, Roberts, Stewart, Wright). These collaborations have led to measurable impacts on health care, the medical device and pharmaceutical industry, and on public policy as elaborated in three of our Impact Case Studies.

The UoA has key industrial collaborators at a local and international level. Two exemplars of local industrial collaboration are the development of new nano-sized inorganic materials for Keeling & Walker Ltd and new "green gas" sensors for Orbital Gas Systems. Keeling & Walker Ltd is the world's largest producer of tin oxide and these new materials helped them to produce near infrared absorbers that can be incorporated into transparent films or coatings for application in agriculture, security inks and laser marking. Orbital Gas Systems is one of the world's leading engineers of industrial gas installations, who have set up a living laboratory at Keele as part of the Keele University located £7M HyDeploy project. The UoA further collaborates with industrial partners across the full range of enterprises from large to micro. Large multinationals include Abbvie Ltd, Allergan Ltd, AMS Sensors AG, Astra Zeneca, Johnson Matthey PLC, Medtronic Ltd, Siemens, Terumo BCT, Unilever and Wienerberger Ltd. SMEs include Baker Ruskinn Ltd, The Electrospinning Company Ltd, Keeling & Walker Ltd, Thermal Ceramics UK Ltd and TurboBeads LLC, and micro-companies include Halo X Ray Technologies, Nanoscience Laboratories Ltd, Pneumacare Ltd and Xenogesis Ltd.

Key academic collaborators are found within other submitting UoA's in Keele, nationally and internationally. Within Keele, the UoA works closely with other disciplines, in particular with the Schools of Allied Health Professions, Computing and Mathematics, Medicine, and Life Sciences, with whom we have joint PhD students and grants. On a university-wide level we work with the Institute for Sustainable Futures (a major, pan-institutional interdisciplinary institute) and the Smart Energy Network Demonstrator (SEND) project. The latter represents an investment of £13.5M into the University, and together with the HyDeploy project helped our UoA to secure EU funding to

study technical problems related to hydrogen combustion (EU H2020 ITN POLKA, ref:813367, 2019). Outside Keele, key national collaborators are Loughborough and Nottingham, with whom we form the EPSRC/MRC CDT in Regenerative Medicine, and Aberdeen, Cambridge, Newcastle and York, with whom we form the Versus Arthritis Tissue Engineering and Regenerative Therapies Centre. These collaborations let our students work outside their own institutions and other students work with us, widening their access to equipment, infrastructure and expertise. One achievement from these collaborations is our preclinical research on allogeneic cell therapies, including large-animal studies (McCarthey, Roberts, Wright). Thanks to this preclinical work we are now in a position to plan future clinical trials of allogeneic cell therapies, for instance based around umbilical cord cells.

Other significant academic collaborations within the UK are found within the Universities of Birmingham, Liverpool, Manchester, QMUL, Warwick, Exeter, Cardiff, King's College and Cranfield. These collaborations have enabled us to develop our research into cell therapy, Outside the UK, longstanding successful collaborations exist across the USA (University of Florida, Lawrence Berkeley National Laboratory), the Netherlands (Erasmus University, Rotterdam), France (Sorbonne University (Paris), Marie Curie Institute (Paris), Spain (Imdea (Madrid) Engineering Research Institute of Aragon (Zaragoza)), Turkey (Hacettepe University Ankara), Germany (FAU), Ireland (Trinity (Dublin)), Australia (Monash (Melbourne)), Italy (Salerno, Bologna; Italian Institute of Technology (Genoa)), Peru (Instituto Nacional de Innovación Agraria), Finland (Helsinki), China (Tsinghua, Sichuan, Tongji, Guangzhou, Wuhan Institute of Science and Technology, Yangzhou, Dalian), and Vietnam (Vinmec (Hanoi)).

Over and above these examples of engagement with and impact on our local and international user-collaborators, the UoA's staff also engage with national bodies leading to direct impacts. Our staff made an important contribution to the NICE assessment of Autologous Chondrocyte Implantation (ACI) that took place during the census period and was instrumental in its approval in 2017. ACI was the first regenerative medicine therapy and cell therapy to be approved by NICE, a vital step in making these therapies available not only to patients in the UK but also worldwide because NICE assessments are widely regarded as authoritative. Our work on Alzheimer's, in collaboration with North-American researchers and combining the national synchrotron facilities (Diamond Light Source) and the Advanced Light Source in Berkeley, has led to an increased understanding of the disease and was highlighted by the UKRI in "The impact of UK-US research collaboration".

Contribution to the research base, economy and society

The engagement of our staff with local industry has also led to tangible impacts, including a project with Wienerberger Ltd, Europe's largest brick manufacturer, which improved the production of ~4M bricks per year. We provide training courses for industry, for example the bespoke 2-day course for Keeling & Walker Ltd aligned to the to the MSc Analytical Sciences for Industry. The engagement of the UoA's staff with wider society is also evidenced by its outreach activities. Exemplars are their contributions to local (Pint of Science, Soapbox Science and Stoking Curiosity) and national (Royal Society Summer Science Exhibition) outreach events.

The submitting UoA recognises the importance of contributing to the discipline and the wider research base, and our staff have contributed to this in various ways. Many of our staff sit on the editorial boards of a wide range of journals, not only within the engineering discipline but also in related disciplines, including Quartile 1 journals such as J Phys: Condens Matt, J Sound Vib, Int J Spray Combust Dyn, Heliyon: Chemistry, Sci Rep, PLoS ONE and World J Stem Cells. Our staff are also active in a wide range of national and international grant awarding panels, including the EPSRC responsive mode, CDT and prioritisation panels, the BBSRC Tools and Resources Development Fund panel, the UKRI Future Leaders Fellowships panel, the Engineering Fellowship panel, the British Council grants review board, Horizon 2020 and Research Foundation Flanders.

Our staff also contribute to learned societies and facility working groups, including President of the International Institute of Acoustics and Vibration (Heckl), Chair of the International Centre for

Diffraction Data Bioceramic Committee and subsequently Director at Large for the ICDD (Greenwood), Chairs of the Macrocyclic and Supramolecular Chemistry (Watkinson) and Carbohydrate (Miller) RSC interest groups, Council member of the Tissue Cell and Engineering Society (Forsyth), and User committee and Working group members of the Diamond Light Source (Sule-Soso and Telling). Our staff's contribution to these societies has been recognised in prizes, such as the Presidential Medal of the British Orthopaedic Research Society in 2020 (BORS; Roberts) and TERMIS Clinical Translation Award (Richardson).

The research of our staff led to invitations for high profile **keynote and invited lectures** at national and international conferences. Examples include the International Conference on Magnetic Fluids (2019), Magnetism 2019, Intermag (2018), Frontiers in Biomagnetic Particles (2017), the 34th annual meeting of the Society for Thermal Medicine (2017), Nanomaterials Applied to Life Sciences (2017), Perspectives in Percutaneous Penetration Conference (2016, 2018 & 2020), Gordon Research Conference (New Hampshire, USA, 2015, 2017), International Society for Stratum Corneum Research (2017), TERMIS EU (2017, 2018, 2019), TERMIS world congress (2018), Expert Panel - Drug Repurposing conference (Biochemical Society, 2019), Annual World Cancer Congress (2017) and the Annual Meeting of the RNA Society RNA2016 (Kyoto).

Our staff also work on the programme committees and as **conference chairs** for a diverse range of national and international conferences, including a long-term involvement with the Tissue Engineering and Regenerative Medicine International Society (TERMIS). Recent highlights include the Tissue Engineering and Regenerative Medicine International Society (TERMIS) European Chapter Meeting Manchester 2020, the 2016 Tissue Engineering Congress, the BioMedEng Conference 2019, the Magnetism and Magnetic Materials (MMM) conference 2020, the Medicinal Chemistry stream at the UKPharmSci conference of the Association of Pharmaceutical Sciences of Great Britain (APSGB) and the Platelet Society meeting Cambridge (2019). Tissue and Cell Engineering Conference TCES 2018. All our staff perform **peer review for the full spectrum of journals within the discipline**, including many **Q1 journals** as well as **Q1 journals outside the discipline.**

Many of our staff are members of peer review colleges such as the EPSRC and NERC Peer Review Colleges, and perform regular **peer review of research grant applications** including project and fellowship proposals sent to national bodies such as UKRI (EPSRC, MRC, BBSRC, NC3R), NIHR, the Royal Society, British Council, national charities (British Heart Foundation, British Lung Foundation, Versus Arthritis, Motor Neurone Disease Association, Muscular Dystrophy UK), and international bodies, such as UNESCO, European Science Foundation (College of Expert Reviewers), European Research Council, European Union, Croation Science Foundation, Science Fund of the Republic of Serbia, the French High Council for Evaluation of Research and Higher Education, Association pour la Recherche sur la SLA and Agence Nationale de la Recherche, Italian Ministry of University and Research (Miur), US DoE, Health Research Council of New Zealand.

Our staff have set up a range of cooperation and collaborative arrangements for PGR training, including EU FP7 and H2020 Initial Training Networks, EPSRC/MRC CDTs and formal PGR training collaborations with Wuhan University of Science and Technology (WUST), Yangzhou University and Guangzhou University, all in China. Our experience in partnership training has resulted in our status as preferred partner within, for example, the Programma Operativo Nazionale Ricerca Innovazione Innovative PhDs with industrial characterization in collaboration with Salerno and Teramo Universities and Italy-based SME's.