Institution: Keele University

Unit of Assessment: B15 General Engineering

a. Overview

In 2006, Keele University established the research activity across the campus and its management into Research Institutes which were not aligned with teaching schools. This enabled the formation of multidisciplinary groupings focused on key impact areas. The General Engineering submission is comprised of staff drawn from across two Research Institutes with expertise in biomedical engineering and environmental engineering: the Institute for Science & Technology in Medicine (ISTM) and the Environment, Physical Sciences and Applied Mathematics Research Institute (EPSAM). Research at Keele is strategically managed and administratively supported through these Research Institutes with significant impact on Health and the Environment. The research institutes promote interdisciplinary and multidisciplinary research and in doing so consolidate Keele's standing as a research-led University with a strong tradition of excellence and support in well-defined areas of internationally leading research strength.

Institute of Science and Technology in Medicine

The Institute for Science & Technology in Medicine (ISTM) was formed from a successful research grouping at Keele in Biomedical Engineering and Medical Physics following on from the award of a new medical school with Manchester in 2004 and subsequently as part of Keele's restructuring programme in 2006. ISTM has an international reputation in the field of Biomedical Engineering, having been awarded 5* or 5A in the previous to last three RAEs by the General Engineering panel, and 90% rated as international quality in RAE2008. ISTM has grown significantly in staff numbers spanning multiple disciplines in engineering, physics and biomedical sciences, expanding by 145% since its formation in 2003/04. Research income within the Institute has grown by approximately 25% per annum since the last RAE. Due to the wide range of disciplines covered within ISTM, the submission has been split between three groupings, UoA15 below, basic biomedical and applied health into UoA3 and the biological component into UoA5.

This growth of ISTM is driven by the "bench to bedside" approach to biomedical engineering with multiple disciplinary teams brought together to address key clinical challenges. Our continual expansion has been underpinned by strategic appointments in Keele's Medical School (ranked 2nd in Medicine, Sunday Times) which allowed us to strengthen our multidisciplinary base with the appointment of engineering and physical scientists. Key cross-cutting platforms within Keele are in Ageing and Environmental sustainability which encompass much of the research activities across the Institutes supported by two funding initiatives, EPSRC Bridging the Gap and MRC Centenary Award. During the past period, two new 'state of the art' £5-10 million translational facilities have been built on the partner hospital sites, University Hospital of North Staffordshire (UHNS) and Robert Jones and Agnes Hunt Orthopaedic Hospital (RJAH), which strengthen the 'bench to bedside' with clinical suites, GMP laboratories for handling patients' tissues and research laboratories for wet lab research, technology and instrumentation development.

Over the past assessment period, the quality and quantity of research output has grown based on the strategy laid out in our 2008 submission. The association with the Medical School has enabled an expansion of frontier research and gaining impact into the clinic. As a result, Keele has concentrated its efforts on continuing to attract promising young academics to new lectureships and senior appointments in strategic areas within ISTM. The Institute has been underpinned by a successful EPSRC Centre for Doctoral Training (CDT) between Keele, Loughborough and Nottingham (currently supervision of ~50 PhD students across the sites) which establishes a cross culture of research in the Midlands area and is involved in national and international postgraduate training with an MSc in Biomedical Engineering and in Cell & Tissue Engineering. Recruitment of new staff has focused on excellence with recruitment from leading international and UK institutions including Times Higher Education (THE) Top 200 institutions such as the universities of Harvard (2), Oxford (4), Cambridge (6), Karolinska Institute (32), Manchester (48), Bristol (66), St Andrews (85), Case Western Reserve (93), Trinity College Dublin (117), Nottingham (140), Auckland (173), Dundee (176), and Liverpool (181) (2013 ranking indicated in parentheses).

ISTM recognizes that a key stage of the research process is supporting commercialization of our novel technologies. Since the last RAE, companies including Nanotherics Ltd and Mica Biosystems have been spun-off to commercialize technologies developed at ISTM. These technologies cover new clinically driven innovations in regenerative medicine, therapeutics, orthopaedic surgery and diagnostics. Industrial collaborations are fundamental to our programmes such as our EPSRC

Centre for Innovative Manufacturing; e.g. AstraZeneca, Intercytex, PepTcell, Syngenta, Ceram Research, Ruskinn, Eppendorf, Smith and Nephew, The Electrospinning Company, Instron/TGT, CELLON, TAP Biosystems and Bose. Patent activity has also increased during this REF period with over 12 patents being filed by or granted to members of ISTM since RAE 2008; in addition to our existing portfolio of ~20. A recent award to ISTM includes a Royal Academy of Engineering Enterprise Fellowship for a graduate to commercialize intellectual property from their PhD.

After a period of rapid expansion over the past 5 years, our current strategy is for steady growth over the next 5-10 years whilst we develop our early career researchers. The Institute provides a thriving research environment and a cross-fertilization of disciplines within a clinical environment. We have rare and privileged opportunities facilitated by day-to-day interactions with different medical specialists; clinical trials involving ISTM-led technologies directly feed into a "bench to bedside" pipeline through our Health Services Research Unit (*submitted to UoA3*).

ISTM has an expanding international profile with active exchange networks promoting two-way transfer of researchers, students and know-how within the EU FP6 funded 'EXPERTISSUES' European Network of Excellence, the EU FP7 funded schemes EU/China 'HYANJI NETWORK' (led by Keele), Marie Curie Initial Training Network MAG(NET)IC FUN (led by Regensburg), BIODESIGN (led by Uppsala), GENODISC (led by Oxford), IMPROvED (led by University College Cork), INFRAVEC (led by Imperial College London), EATS (led by ISTM), MYJOINT (led by Keil) and a Marie Curie Training Programme (Alea Jacta EST) (Led by Braga). In addition, we have established partnerships with research active institutions in India (IIT-New Delhi, IIT-Indore) Malaysia (Universite Sains Malaysia), Vietnam (Thai Nguyen University), Saharan Africa (King Saud University), Central and South America (University of the Yucatan (Mexico), University of Sao Paolo (Brazil)). ISTM has expanded its international profile by appointing two joint Professorial positions; in the USA, University of Florida and Europe, J Heyrovsky Institute of Physical Chemistry, Prague, with visiting ISTM professorial appointments; China (Sichuan) and Malaysia (Universite Kebangsan Malaysia).

Research Institute for Environment, Physical Sciences and Applied Mathematics

The Institute for Environment, Physical Science and Applied Mathematics (EPSAM) was formed from a successful grouping of internationally recognised researchers in 2005 from across the physical and natural sciences at Keele. EPSAM has an international reputation in the fields of environment and environmental engineering with 90% of the research in the RAE2008 General Engineering submission rated as international quality. EPSAM has seen significant growth over the REF period with research income rising to around £5M per annum and a 35% growth in research student numbers. Due to the multidisciplinary nature of EPSAM's research separate submissions are being made to UoAs 3, 7, 9, 10 and 11 that complement this submission to UoA15.

The significant growth in EPSAM has been driven by the continued expansion in undergraduate student numbers and strengthened by the provision of a sustainable, multidisciplinary environment for the support and development of research and enterprise activity, which underpins the pure and applied research carried out within EPSAM. The growth in PGR student numbers has been supported by an institutional matched funding scheme (Acorn - £450k per annum) and other initiatives such as fee waivers and bursaries for international PGRs. Keele has an ambitious sustainability agenda, and research in environment and sustainability is a key pan-University theme. This has already led to several new appointments from internationally renowned institutions including THE Top 200 institutions such as the universities of British Columbia (31), McGill (35), St. Andrews (117) and the Max Planck Institute of Colloids and Interfaces. The international profile of EPSAM has resulted in numerous collaborative projects, including with research active institutions in Canada (UBC), India (IIT Madras, IIT Delhi, IIT Hyderabad), China (Nanjing University), Brazil (Federal University of Sergipe), Japan and France (Institut Laue-Langevin (ILL) and ESRF).

Commercialization of the institutes' research is a major goal, and to aid this significant funding has been received from industrial partners including AstraZeneca, British Gas, Cairn Energy, Rolls-Royce, AMSTED as well as AWE, CTBTO, ILL and government departments (DECC, DEFRA), MOD, and local authorities. EPSAM currently has made 3 patents or applications made since the last RAE, with one spin-out company in environmental engineering. Significant funding has been secured from the EU, RCUK (EPSRC, NERC, ESRC, STFC), the Royal Society, Leverhulme.

b. Research strategy

1) ***ISTM*** aims to improve the health of patients by applying knowledge gained from basic science to develop insights into the causes of disease and thus novel therapies. This ***"bench to bedside"***

approach brings together engineers and physicists and NHS clinicians from a range of backgrounds and specialties, in a high quality research environment with access to the latest facilities. Research performed within the ISTM General Engineering grouping falls within three broad and interlocking sub-groupings; Bioengineering and Regenerative Medicine, Biomagnetics and Nanomedicine, and Diagnostics engineering and Proteomics. The structure of the research comprises a number of strongly interacting teams across theme and discipline boundaries.

Bioengineering and Regenerative Medicine (***El Haj, Forsyth, Kuiper, Kuiper, Roberts, Richardson, Fricker, Gates, Kehoe, Wright, Blana, Chadwick, Furness, Stewart***) This group focuses on the development of enabling technologies in cell and tissue engineering through to applied clinical research in regenerative medicine and rehabilitation. The study of cellular phenomena and materials in clinical applications such as autologous treatments and surgical repair is a major focus with strong underpinning from the engineering field. Our research into the use of engineered tissues for replacement surgery is world class and paving the way to adoption of these therapies in the clinic. Notable innovations include bioreactor design, hypoxic work stations for stem cells, stem cell control systems, novel stem cell formulations, mechanically tuned scaffolds and novel 3D engineered tissues in orthopaedics, neuroscience and haematology. These technologies feed into clinical programmes which cover cell based therapies and human biomechanics. A new development over the assessment period is the recruitment of early career staff (Blana, Chadwick) to expand our research in cellular biomechanics to tissue and whole body biomechanics and form links to our clinical rehabilitation unit, Orthotic Research and Locomotor Assessment Unit (ORLAU) and our research into cell therapies for Rheumatoid Arthritis (Kehoe).

The Bioengineering and Regenerative medicine grouping has been awarded several Centre programme grants. The group has received EU funding to become a ***European Centre of Excellence in Tissue Engineering.*** The group forms part of three Centres, the ***Arthritis Research UK Centre for Tissue Engineering*** with Newcastle, York, and Aberdeen, the ***EPSRC Centre for Innovative Manufacturing in Regenerative Medicine*** with Loughborough and Nottingham, and the ***EPSRC CDT in Regenerative Medicine*** also with Nottingham and Loughborough. The group has been successful in receiving a pipeline of funding for fellowships in Regenerative Medicine with the ***EPSRC E-TERM Fellowship Scheme*** which links 6 Universities in the Midlands and North West. Keele specifically has 15 PhDs on the CDT programme and currently supervises 3 postdoctoral fellows through the E-TERM scheme. Recent awards include funding from ***MRC UK Regenerative Medicine Hubs*** within the Stem cell niche and the Delivery platform and a Royal Society Merit Award.

In 2004, the group established the 10 year, MRC multi-centre **ACTIVE** clinical trial on autologous chondrocyte implantation which is the first UK multi-centre trial in cell therapies and links 22 orthopaedic centres across Europe which is due to report in 2014. Keele University was an early adopter of cell therapy in the UK with clean rooms and REC-approved projects dating back to the late 1990's. Full regulatory approvals - Human Tissue Authority (HTA) and Medicines & Healthcare Products Regulatory Agency (MHRA) - are in place to support these activities at the RJAH campus. This programme has been augmented by additional grant funding from the ARUK (2011-2015) and MRC (2014-2017) to carry out a phase 1 trial, **ASCOT,** designed to compare the clinical benefit of cell therapy strategies (autologous stem cells, chondrocytes). To complement these activities, a clean room was commissioned at the UHNS campus. These rooms will support the application of stem cells in therapies to treat musculoskeletal and neurological conditions (Impact story 1). The extension of cell therapy expertise into neurological conditions complements the internationally recognized neuroscience within ISTM and collaborations with Athersys and Reneuron are commencing 'first in man' cell therapy trials in our UHNS Stroke network.

A notable element of this group is the strong programme in biomechanics and rehabilitation which spans the cell, tissue and whole body level. Understanding cellular biomechanics and applying this knowledge to tissue engineering and design of bioreactors has been supported by a BBSRC LOLA "Longer and Larger" award, EPSRC responsive mode and "Creativity at Home" schemes. Scalable biomechanics feeds through to the tissue and whole body level with expertise in the development of upper and lower limb musculoskeletal models, and in the application of those models to understanding and replacing lost function due to disease or injury in the clinic. The group is aligned to clinical practice through the ORLAU Institute based at Oswestry which uses clinical prospective data for assessment of gait and the impact of interventions (Impact Story 2).

Biomagnetics and Nanomedicine (***Dobson, Roach, Telling, Chari, Hoskins, Yang, Kuiper,***

Harper, El Haj) The design of nanotechnology approaches to biomedicine has been a major platform of research within ISTM. New nanomaterials, surface design and nanoparticle formulations, both magnetic and polymer based, have been designed with funding from the EPSRC, BBSRC, MRC, UKRC, NIH (USA), Royal Society and EU FP7. This has been coupled to a benchmarking approach in the development of nanomagnetic technology for drug, gene and cell targeting with technology spun-out into nanoTherics, and to the design of novel bioreactors using magnetic fields applied to ferrofluids and cells that have been tagged with magnetic nanoparticles – this technology was spun-out into MICA Biosystems. In addition, key areas of innovation over the past assessment period include new material formulations for controllable degradation profiles, nanofibre and electrospinning technologies.

The institute now has an established international reputation in the application of magnetic **nanotechnology** with applications in regenerative medicine, cancer and imaging. Further to this, new forms of magnetic nanoparticles with tailored magnetic properties are being developed for advanced cancer therapy applications and enhanced magnetic resonance imaging (MRI) performance. Current projects in this area include the use of bacteria-derived metal substituted iron oxide nanoparticles, and synthetic engineered multilayer nanodiscs. The work includes nanotechnology approaches to surface and materials construction used for tissue engineering applications. Recent EU platforms (**MagNETicFUN**) have provided the grouping with a European network for Keele. Other funding includes a BBSRC New Investigator Award, RCUK Academic Fellowship, Marie Curie Fellowship, NIH (USA) funding and a Royal Society Merit Award.

Diagnostic Engineering and Proteomics (***Smith, Spanel, Semenov, Greenhough, Li, Hart, Forsyth, Rutten, Fuller, Sule-Suso, Teixeira, Thompson).*** Diagnostics and Proteomics has experienced significant growth since the last RAE with funding drawn from the EPSRC, NIH(USA), Welcome and NIHR. Programmes range from new instrumentation development e.g. Selected Ion Flow Tube – Mass Spectrometry (SIFT-MS) and Microwave Imaging, which are close to clinic, through to basic science research. The latter includes structural biology and mass spectroscopy-based proteomics which have defined novel biomarker strategies for disease detection and screening. Members of this theme have strong national and international ties through collaborations with the Universities of Cambridge, Nottingham, Sheffield, Newcastle, Southampton, Oxford, UCL, Imperial College, University of Florida, University of Hawaii, ETH-Zurich, The Royal Institute-Stockholm, MIT, The University of Western Australia, Czech Academy of Sciences, The US National High Magnetic Field Laboratory (NHMFL) and The Advanced Photon Source (APS) Synchrotron at Argonne National Laboratory (ANL) in Chicago and in an example of cross-RI collaboration group members are drawn from both EPSAM and ISTM. Approximately 41% (22/54) of publications offered for consideration as outputs in this submission to B15 incorporate international co-authorship.

Within this group there is a substantial expertise in structural biology, proteomics and synchrotron radiation with a key aim of establishing biomarkers for clinical applications. This expertise is reflected in strong, long-term, fundamental, global provision of scientific, management and technical expertise in Synchotron radiation and Neutron scattering central facilities including Oak Ridge National Laboratory (USA), Los Alamos Neutron Scattering Centre (USA), Institut Laue Langevin (Grenoble), Daresbury (UK), and Diamond (UK). Current studies include investigating protein structure, function and interactions, methods and applications for proteome analysis, vibrational, Fourier Transform Infrared, and raman spectroscopy as diagnostic tools in cancer, biomarkers for lung cancer and diabetes, drug discovery, DNA and its complexes with drugs and proteins and methodological developments for neutron and X-ray scattering. The structural biology group leads the Midlands UK Structural Biology consortium, including Warwick, Leicester, Nottingham, Birmingham and Keele, at Diamond. Keele is also based at Institut Laue Langevin in Grenoble developing new methodologies and designs for X-ray and neutron scattering techniques to study the structure of DNA, its biomolecular interactions and biopolymer investigations.

Instrumentation development for clinical applications is key to this grouping. Examples include the development of analytical instruments that exploit gas phase ionic reactions for the analysis of trace gases in breath for non-invasive clinical diagnosis and therapeutic monitoring. SIFT-MS allows on-line, real time analyses of the trace gases and are now being manufactured and sold into clinical environments (Impact story 3). Microwave imaging has been developed through NIH funding with the North Carolina Institute. Recent successful large animal trials have led to human trials aiming to commence in March 2014. The technology is being exploited by EMImaging LLC

and aims to detect blood embolisms following stroke. The instrument will be located in mobile ambulances with remote instantaneous on line transfer and interpretation from a central clinical unit in Europe.

2) ***EPSAM*** aims to develop a multidisciplinary approach to environmental sustainability by bringing together scientists with a broad range of expertise. A high quality research infrastructure is provided with state of the art facilities and a continual investment in resources, staff and PGR students. The EPSAM General Engineering submission is within Environmental Engineering and whose major research themes are described below.

Environmental engineering (***Darton, Egger, Hollamby, Jackson, Ormerod, Radu***).This sub group of research at EPSAM develops environmental technologies and sustainable materials for advanced applications. The group has received funding from EPSRC, STFC, ESRC, EU, Royal Society as well as industry including Atomic Weapons Establishment (AWE), BASF, SciSite and Ciba Speciality Chemicals. Underpinning much of this research are advanced spectroscopic, analytical and computational techniques to environmental science and structural materials chemistry issues. (Impact story 4). The environmental engineering subgroup has seen significant growth since the last RAE with the appointment of 3 new lecturers (Darton, Hollamby, Radu) and has active research interests in catalysis, solid oxide fuel cells (SOFCs), sustainable technologies, sensors, porous and functional sustainable materials, structural characterization and computational modelling. Much of this work is carried out through collaborations with both national and international partners that have led to joint publications and/or funding applications including the Universities of Glasgow, St Andrews, Birmingham, Loughborough, British Columbia, Lille, Paris-Sud, Nanjing, Clark, Geneva, Yale and IIT Madras, IIT Delhi, IIT Hyderabad, UCLA and Johnson Matthey. To support these activities the group make extensive use of central facilities including ISIS, Diamond and ESRF, which complement the facilities available within the recently refurbished Birchall Centre for Materials Chemistry.

Within this subgroup there is substantial expertise in environmental catalysis and sustainable materials and this is reflected in studies on heterogeneous catalysis for environmental applications and development of SOFC materials, synthesis of microporous and mesoporous materials and the development of nanoporous aminoresins for industrial applications, hydrothermal synthesis of metal oxides and computational modelling of nuclear materials. This work is complemented with recent expansion in ionophore based sensors that has already attracted an EU IRSES grant, the self-assembly of soft materials and the development of organo-electronics, which have strengthened research in environmental analysis and engineering materials. The development and application of instrumentation and techniques for the characterisation of materials underpins much of the research and the group have an international reputation for the development of neutron, infrared and solid state NMR spectroscopic methodologies for the study of microporous and mesoporous materials, which has attracted significant funding from STFC and ESRF.

c. People:

Within each group there are a number of key and associated staff. These are listed below;

Bioengineering and Regenerative Medicine

Key staff; Prof Alicia El Haj (Institute Director) (AEH), Dr Dimitra Blana, Dr Ed Chadwick (EC), Dr Nicholas R. Forsyth (Theme Lead) (NRF), Dr Rose Fricker (RF), Dr David Furness, Dr Monte Gates, Dr Alan Harper, Dr Oksana Kehoe, Dr Jan-Herman Kuiper (JHK), Dr Nicola J Kuiper, Prof James Richardson (Clinical Theme lead) (JBR), Prof Sally Roberts (SR), Dr Caroline Stewart (CS), Dr Karina Wright.

Associated staff; Prof Jon Dobson (JD), Dr Heidi Fuller, Prof David Smith FRS, Prof Patrick Spanel (PS), Dr Josep Sule-Suso (JSS), Dr Wen Wu Li, Dr Ying Yang (YY), Dr Divya Chari.

Biomagnetics and Nanomedicine

Key staff; Prof Jon Dobson, Prof Alicia El Haj (Institute Director), Dr Divya Chari, Dr Clare Hoskins, Dr Neil Telling (NT), Dr Paul Roach, Dr Ying Yang.

Associated staff; Dr Nicholas R. Forsyth (Theme Lead) (NRF), Dr Rose Fricker, Dr David Furness, Dr Monte Gates, Dr Oksana Kehoe, Prof James Richardson (Clinical Theme lead).

Diagnostic engineering and Proteomics

Key staff; Prof V Trevor Forsyth (VTF), Dr Heidi Fuller, Prof Trevor Greenhough (TJG), Dr Sarah Hart (SH), Dr Wen Wu Li, Dr Frank Rutten (FR), Prof Sergei Semenov (SS), Prof David Smith FRS, Prof Patrick Spanel, Dr Susana Teixeira (ST), Dr David Thompson.

Associated staff; Dr Divya M Chari, Dr Nicholas R. Forsyth (Theme Lead), Dr Rose Fricker, Dr

Paul Roach, Dr Ying Yang.

Environmental Engineering

Key staff; Dr Richard Darton (RJD), Dr Chrstelle Egger, Dr Martin Hollamby, Dr Robert Jackson (RAJ), Prof Mark Ormerod (RMO), Dr Aleksander Radu (AR).

i. Staffing strategy and staff development

Excellence in research is an essential criterion in all new appointments. The strategy for appointment of new academic and research staff adopts a dual perspective. Core requirements are first identified to ensure maintenance of strength in essential disciplines followed by alignment with strategic institutional growth areas. The adoption of this dual perspective permits both stability and growth. Importantly ISTM and EPSAM members enjoy flexible, family-friendly working arrangements, and benefit from a revised appraisal system that is designed to reward excellence and identify development needs. In 2013 ISTM and Keele University received the Bronze Athena Swan award and achieved the European Commission HR Excellence in Research Award.

Staff development is a priority within both ISTM and EPSAM. All newly appointed academics are aligned with dual mentors to provide support in both teaching and research. This mentoring approach engenders support to the new academic while developing the skills associated with maintenance of a balanced portfolio. Research mentoring is provided from within the identified 'best fit' research theme and supplemented by the activities of the Theme Leads who review all grant applications and help in identifying the most suitable funding schemes.

The staff strategy and development program supports career progression through both internal promotion and supporting applications elsewhere where appropriate. In the 2008 submission we submitted 29 ECR of who 6 have since been promoted to Senior Lecturer, with a subset of 3 subsequently promoted to Reader, and 3 have been promoted directly to Reader. Within all other staff submitted in 2008 we have supported promotion to Senior Lecturer, Reader and Professor. An annual program of appraisals encourages staff advancement through a positive review process. Our Athena Swan programme ensures equal opportunities for all staff. In addition to support of career advancement we have also been supportive of career progression through relocation to alternative employment where 8 staff listed as ECR in 2008 have moved to positions at other institutions including to Manchester, Warwick, Aston, Lancaster, Birmingham, Sussex and Victoria. Many of these former staff members have retained honorary contracts at Keele and continue to collaborate extensively.

ii. Research students

Postgraduate research students in both ISTM and EPSAM receive a high quality training which encompasses personal development, transferable, employability, scientific and subject specific skills in accord with the Vitae Researcher Development Framework. Training is delivered through the Learning and Professional Development Centre, the research institute, the research theme and the research group, complemented by modules and courses delivered by other RIs, other faculties, and the Schools and Departments of the University. Each Research student maintains a Personal Development and Learning plan (PDLP) which details training requirements and aspirations, along with the preferred routes to acquiring particular skills and reflection on the effectiveness of training undertaken. The EPSRC CDT in Regenerative Medicine provides a four year training opportunity which spans 3 Midlands Universities with the first year focused on mini-courses and mini-projects alongside key training in business plan development and generic career skills.

Comprehensive training in the appropriate subject-specific skills and techniques is provided through both formal modules and the research theme and group, which includes the student's supervisor(s), other academic and research staff, technicians and other students. Formal modular training can be taken in areas such as mathematics and medical statistics, engineering and laboratory techniques that are part of the ISTM Masters and Marie Curie training courses. In addition, the ISTM Research Training programme brings the student into contact with the full multidisciplinary range of subject-specific expertise in the research institute, and students are typically keen to see at first-hand the approaches used by scientists outside their own field. The research themes in ISTM are distributed across different laboratories and sites, exposing student members to a range of cross-disciplinary approaches to projects in their broad area of interest, and encouraging visits and the interchange of ideas. Most ISTM seminars are organised at theme level, and encourage regular meetings of lab-based members, clinical colleagues and industrial contacts

from the 4 campus Innovation Centres.

Within EPSAM each PGR student is in a research cluster as well as an individual research group which provides an excellent and integrated research environment. Research training for PGRs is based around a bespoke, student-focussed continuous development system, which reflects the training and personal development needs of individual PGR students and is managed through an on-going personal development and learning plan. All students within EPSAM participate in generic research training that addresses the Research Councils' agendas for key and transferable skills. In addition to giving internal presentations, students are encouraged, and funded, to make regular conference presentations and attend advanced training courses both in the UK and overseas. EPSAM also runs a range of subject specific internal and external seminars that are available to all PGR students to encourage multidisciplinary research and discussions.

While the research institutes have overall responsibility for each of their students training, the Keele Learning and Professional Development Centre takes an overview of Employability and Personal Development skills training, identifying requirements and facilitating provision of courses to meet these requirements. This approach is complemented by optional modules and workshops provided by other RIs, and by Vitae. The research environment also plays a major role in the development of generic skills, many of which are developed during the course of the research through informal mechanisms including self-direction, supervisor support, mentoring and conferences. Through discussion, encouragement, advice and reflective practice, the research institute places particular emphasis on team work, the group ethos and personal development, leading to the development of a wide range of personal, networking, team-work and communication skills. Students are encouraged to: recognise their own strengths and weaknesses, seek advice and support when appropriate, work effectively and perceptively with colleagues and peers, contribute scientific, administrative and personal skills to the group effort and environment, demonstrate an open-minded, flexible approach to learning and research; work independently and thoroughly, understand the value of teamwork and the benefits of consensus and the group ethos.
In line with the RCUK Joint statement, ISTM and EPSAM proactively ensure that the development of wider employment-related skills does not detract from the core objectives of training in research skills and techniques and a substantial original contribution to knowledge.

d. Income, infrastructure and facilities

Income: ISTM and EPSAM have both performed extremely well in the period spanning from the last RAE in an increasingly competitive market. Over the census period ISTM has been awarded ~£19M in new revenue, as per HEFCE guidelines, with annual income figures holding steady in an increasingly competitive funding market (an averaged £3.8M per annum). During that period the major funding sources have included BBSRC (£1.1M), Wellcome Trust (£1.7M), EU (£1.3M), MRC (£1.9M), EPSRC (£1M), NIHR (£2.9M), ARC (£900k), STFC (£350k); industrial sponsors have included Bayer, Merck, Wyeth, Eli Lilly, TEVA Pharmaceuticals, GlaxoSmithkline, Hoffman La Roche, Amgen, Novartis, Harlan Labs, TGT, Ruskinn, Serono Labs, Allergan, UCB Biosciences, Vifor Pharma, Baxter, Ceram, MI Engineering, Synthon, Pfizer, Avanir Pharma, Abbvie, and Outcome Europe amongst others (over £2M).

Over the census period, EPSAM has received ~£22M in new revenue with annual income figures showing a steady increase (an averaged £4.5M per annum). During that period the major funding sources have included, for example, EU (£3M), EPSRC (£1.3M), NERC (£1M), ESRC (£371k), STFC (£13M) and industrial sponsors have included Spritzer, Astra Zeneca, Nexia, Cairn Energy, National Grid Carbon, Endurance Wind Power, Reactec, Amsted Rail Company, Nestec, BASF, Atomic Weapons Establishment and Ciba Specialty Chemicals (over £1.1M).

Infrastructure and Facilities: Research within ISTM is performed across three primary sites; Guy Hilton Research Centre (GHRC) (a purpose built £10M research facility supporting biomaterials, tissue engineering research and clinical interface based at the UHNS via provision of consulting rooms and cell therapy grade clean rooms – fully opened in 2008), Huxley building (research site located on main campus supporting synchrotron, proteomics, and neuroengineering research), and RJAH (featuring ORLAU and the state-of-the-art £10M TORCH Arthritis research centre, opened in 2009). In addition to equipment purchased through grant income ISTM is proactive in maintaining a state-of-the-art research space and has receives and internally competitive award of ~£0.5M per annum from central University funds.

Patient Research facilities are located at the GHRC and RJAH providing specialised patient research suites with consulting rooms, all ancillary services and waiting areas, ideal for hosting clinical studies including clinical trials. Human Genomics facilities are located at both clinical campuses providing dedicated space and equipment for whole-genome analysis and gene expression characterisation with an Affymetrix workstation an array of real-time PCR analysis devices. High-throughput sequencing (ABI) and mutation analysis based on Wave (Transgenomics) and Pyrosequencing technologies and Cell sorting and cell cycle (FACS) analysis. Structural Biology facilities have undergone recent refurbishments and now provide coherent research facilities and laboratories for structural biology including a new purpose-built X-ray room, a protein biochemistry laboratory, a walk-in cold room, a graphics room (PCs, SGI O2+s, SGI Octane) and a dedicated resource room. Access to the SRS, ESRF and Diamond is provided through the Midlands UK Protein Crystallography Consortium. Electron Microscopy facilities services include electron microscopy, image processing. Confocal/two photon imaging (BioRad MRC1024), Field emission SEM (Hitachi S4500), Conventional TEM (JEOL100CX and JEOL1230, Megaview III (SIS systems)), and X-ray microanalysis (JEOL 100CX). Proteomic Mass Spectrometry facilities include a 4800 MALDI TOF/TOF and 3200 QTRAP tandem quadrupole mass spectrometers, with nanoflow HPLC interfaces.

ISTM facilities include a wide range of equipment for the multi-scale analysis and application of forces as well as *in vivo* analysis of movement and function, both in-house and through collaborations with other university departments (Schools of Health and Rehabilitation, Mathematics & Computing), UHNS Orthopaedics Department and ORLAU (RJAH). These include Bioreactors; Bose ElectroForce, TGT Hydrostatic, 4-point bending, compression/perfusion, Flexercell, magnetic force bioreactor (Mica Biosystems), nanoTherics, and indentation systems. *In vitro* characterisation facilities include the integrated component of the Bioreactors listed above and systems such as optical coherence tomography, birefringence microscopy, AFM, FTIR (iS50 NICOLET), Raman microscopy (DXR, Thermo), optical tweezers, multiple fluorescent microscopes (Eclipse Ti) and µCT40 (Scanco Medical). Measurement of function in musculoskeletal biomechanics is performed with state-of-the-art optical (both 8 and 12-camera Vicon MX systems, Vicon Motion Systems Ltd) and portable inertial (Xsens MTx, Xsens Technologies BV.) motion tracking systems, AMTI (Advanced Mechanical Technology, Inc.) and Kistler force plates, foot pressure plates (Biovec Force Measurement, AMTI), and a tendon/ligament materials testing machine (ESH 5kN). Neuromuscular studies are supported by bipolar (Biometrics Datalink and Datalog, Biometrics Ltd.), high-density (TMSi Porti, Twente Medical Systems International B.V.), and 16-channel Trigno wireless (Delsys Inc.) surface EMG systems and a portable cardiopulmonary stress testing system (Oxycon Mobile, CareFusion Corporation). The facilities also include a fabrication workshop where customised measurement and orthotic devices are developed. Translation is achieved via clinical trials and links with local industrial partners.

Research within EPSAM is carried out across two sites located on the main university campus; Lennard-Jones Laboratories (which houses the Birchall Centre for Inorganic and Materials Chemistry) and the William Smith building both of which support environmental engineering research. The group has continued to benefit from considerable university support and significant financial investment in new equipment, with EPSAM receiving around £1M from central university funds in the last two years.

The recently refurbished Birchall Centre for Inorganic Materials Chemistry is located within the Lennard-Jones Laboratories and provides a dedicated research environment for all aspects of environmental and materials chemistry research. The centre is well equipped with a dedicated clean room for trace element analysis, a furnace room for high temperature and hydrothermal synthesis and contains a range of facilities for catalytic and fuel cell testing. This is supported by a range of state of the art equipment within the Lennard-Jones laboratories including powder X-ray diffractometer, FTIR spectrometers, Raman microscope, ICP-OES, ICP-MS, X-ray photoelectron spectrometer, gas sorption and pore size analyser and mercury porosimeter. Structural characterisation work is supported by frequent use of Diamond, ISIS and the ESRF and is complemented by the recent purchase of advanced solid state NMR facilities (Bruker Advance III HD 400 MHz). Recent refurbishment of the laboratories has provided dedicated access to electron microscopy facilities (Hitachi TM3000 SEM), X-ray fluorescence analysis, CHNS and O analyser.

e. Collaboration and contribution to the discipline or research base

Keele University is research focused with delivery ambitions reaching across global communities. EPSAM and ISTM are both heavily invested in delivering this ambition through key collaborations such as the EPSRC Bridging the Gap programme, joint appointments, and strategic positioning within local, national, and international societies. In addition to those examples provided above, ISTM staff members play a crucial role in the EPSRC-funded CTD for Regenerative Medicine and the IMRC in Regenerative Medicine (both led by Loughborough University) and in two of the recently awarded UKRMP hubs (Niche (Edinburgh-led) and Acellular (Nottingham-led). A current Keele-led application is through to the second round for a £4 million MRC Disease focused programme linking 5 Universities in the UK with 3 in Netherlands.

Key collaborations held by staff members are reflected within the preceding sections and include prominent research centres located in the UK (Cambridge, Oxford, UCL, Edinburgh, Glasgow), USA (University of Florida, University of Hawaii, The US National High Magnetic Field Laboratory (NHMFL), MIT, Yale), Europe (ETH-Zurich, The Royal Institute-Stockholm, Pisa, Upsala), China (Sichuan, Nanjing, Tsinghua and Guangzhou University and India (IIT New Delhi, IIT Indore, IIT Madras, IIT Hyderabad). International collaborations are reflected in a number of key, strategic, joint and guest appointments in renowned institutions. These include Malaysia (AEH), China (NRF, YY), USA (University of Florida (JD), University of North Carolina (SS), Europe (Czech Academy of Sciences (PS), Institut Laue Langevin, Grenoble (ST, VTF). The importance of these collaborations is reflected in more than 50% of ISTM (58/105) and EPSAM (12/23) of the publications returned have international co-authors.

Societies and facility working groups perform a dominant role in maintaining focus and drive within disciplines and ISTM and EPSAM academics have delivered crucial roles within many of these during the reporting period. These include Executive Committee membership of ISB (EC), Chair of TERMIS (Europe) (AEH), Chair of the International Shoulder Group (EC), Cellular Engineering Working Group member of IFMBE (AEH), IPEM Academic Advisory board (AEH), IPEM Special Interest Group member (JHK), MRC DPFS Panel member (AEH), MRC - College of Experts (JBR, AEH), General Engineering UK REF 2014 Panel (AEH), H2FC Supergen Science Board (RMO), MSCA committee member (NRF), Midlands UK Structural Biology consortium lead (TJG), British Mass Spectrometry Society committee member (SH), Member UK Stem Cell Advisory Panel (AEH), ARC UK Research Board member (JBR), AMR board member (JBR), ICRS board member (JBR), SPIE committee member (YY), EPSRC SAT Healthcare and SAN member (AEH), Chair of Beamline Working Group and User Committee member at Diamond synchrotron (JSS), Peer Review Committee and expert member at Soleil synchrotron, France (JSS), Magnetism Group Committee at Institute of Physics (NT), Beamline 10 Working group at Diamond Light Source (NT), Member of EPSRC Network on Magnetic Superlattices (NT), SSBII committee member and website coordinator (FR), Special Interest Group committee member for Ambient mass spectrometry of the BMSS (FR), Chair of CMAS Standards Committee (CS), ESMAC teaching faculty member (CS), Scientific Advisory Panel for AMR (CS), BBSRC BBS panel, Deputy chair (AEH), Parkinson's Disease Society research advisory panel (RF), UKIERI funding panel (RMO), EPSRC peer review college member (RAJ, AEH), Chair of RSC Solid State Group committee (RAJ), ILL Structure and Dynamics of Biological Molecules proposal review committee (ST), Panel Member of FRM2 Biology Review Committee for the Neutron Research Facilities in Munich (ST), RSC Solid State Group committee (RJD), RSC Environmental Chemistry Group committee (AR).

Editorial board membership plays an essential role in serving the academic community. Editorial board positions across the reporting period include those at ISRN Nanomaterials, IEEE Transactions on NanoBioscience, Nanotechnology, Science & Applications, Journal of Bioengineering and Biomedical Science, International Journal of Clinical & Experimental Medicine, American Journal Alzheimer's Disease & Other Dementias, Journal of Alzheimer's Disease, Electromagnetic Biology and Medicine, The Open Biomedical Engineering Journal, The Open Gene Therapy Journal, Recent Patents in DNA and Gene Sequences, Tissue Engineering, Journal of Tissue Engineering and Regenerative Medicine, World Journal of Stem Cells, Neuromuscular Disorders, Translational Neuroscience, Hip International, Journal of Powder Coating, and the Journal of Breath Research, NeuroReport (Editor-in-Chief), and Medical Engineering and Physics.