Institution: Nottingham Trent University

Unit of Assessment: B15 General Engineering

a. Overview : We present our high quality research activity under two thematic areas: (a) Imaging and Sensing including: Security x-ray imaging; Magnetic resonance, relaxation and imaging; Advanced optical imaging and; Acoustics and vibrometry; (b) Bio-materials and Materials Engineering including: Electronic and photonic materials; Solid/liquid interfacial science; Multi-functional materials synthesis and properties; and Bio-functional/derived/inspired materials. Our submission to unit B15 General Engineering is within its remit for "Multi-Disciplinary and Inter-disciplinary research". Our excellent research is performed by staff across Bio- and Electrical Engineering and the Applied Sciences within the University's ***School of Science and Technology*** (one of 9 schools) which facilitates multi-disciplinary collaborations and joint infrastructure operation and investment. Our ***Engineering Advisory Group*** includes senior staff from the Unit and the School and provides strategic management, along with targeted support and mentoring.

b. Research strategy

b1. Current position with reference to position in RAE2008

The outcome of our RAE2008/UoA25 Engineering submission included 55% of activity at grades 3* and 4*; this was high quality on a relatively small core of 10 FTE of category A staff. In addition to continuing high quality research/outputs, achievements of our unit for REF2014 include:

- Significant increase in research activity to 15 category A staff (14.4 FTE, includes 7 from RAE)
- Growth in research income from £0.68M pa (2001/02-06/07) up to £1.42M pa (2008/09-12/13)

Our thematic areas have developed coherently throughout the RAE and REF periods, enabled by strategic support, infrastructure investment and growth in income, collaborations and staffing.

b2. Evidence of achievement of strategic aims during 2008-2013

The forward-looking strategy in our RAE2008 submission (RA5a/A2.3) included to: perform inter-disciplinary research, exploit synergies with our Biomedical Unit (UoA12/RAE2008, 50% at 3*/4*); attract diverse funding sources; leverage high quality niche research to maintain external income and researcher numbers. Objectives 1–3 below underpin this strategy, with Obj. 4 added in period.

Objective 1: ***Increase research activity by strengthening areas of research excellence***
(a) Imaging: New niche MRI research was established by *Bencsik*, *Newton* and *Morris* and adding two MRI scanners; *Evans* x-ray activity was strengthened with laboratories (155m^2 total) and equipment in our new £4.4M Rosalind Franklin building (2012). (b) Materials: Staff appointments strengthened all research areas, i.e. *Castleton* in Electronic/photonic materials; *Ouali* and *Fairhurst* in Solid/liquid interfacial science; *Martin* in Multi-functional materials synthesis and properties; and Prof *Stevens*, appointed from STFC bringing extensive collaborations in bio-nano-materials.

Objective 2: ***Cultivate collaborative multi- and cross-disciplinary research with impact***
Active support for staff to apply their expertise across traditional discipline boundaries included cross-Science/University seminars, annual networking events and funding for PhD projects with co-supervisors in other units, e.g. *Perry* and Rees (UoA A03 on cancer research). RCUK funded multi-disciplinary research included: OCT for art (Dunhuang Academy in China, National Gallery, British Museum, English Heritage, AHRC AH/H032665/1); Smart materials work with UoA D34 (EPSRC Cross-Disciplinary Feasibility Account EP/I016414/1); drag assessment before the Olympics (UK Sport, Royal Yachting Association, Southampton Univ Wolfson Marine Unit, EP/G057265/1, EP/G058318/1, and EP/E063489/1 EPSRC Platform Grant) and drag reduction with Univ Alberta Canada (*Newton*); and type 2 diabetes testing (Cardiff Univ, Welsh NISCHR, STFC ST/K001829/1). As well as the high quality outputs in REF2, published collaborative research (e.g. *Euro. J. Soil*, *PLOS ONE*, *Planta*) encompassed: *Forensic* and *Environmental Science* (pistol barrel ID, ozone and wastewater monitoring); *Medicine* (bactericidal metal ions, nanoparticle cell labelling, biomedical spider silk); *Animal/Plant Biology* (US/Canadian wolf howling, snail adhesion/locomotion, lichen water repellency); *Geology* (soil drainage); and *Archaeology* (ancient Egyptian faience structure).

Objective 3: ***Grow and diversify the research income and funding portfolio***
Assisted by the NTU Grant Capture Team (brokering new relationships, pursuing funding opportunities) we achieved increases in income from UK Research Councils by ×2.5 to £810k/year,

from UK Government bodies by ×2.1 to £181k/year, from European Union by ×3.6 to £173k/year, and from overseas by ×1.4 to £157k/year (comparing REF2014 FY2008/09-12/13 to RAE2008 FY2001/02-06/07). Income continues to grow, with grants of value £1.87M to the unit started in FY 2012/13 and of value £1.0M plus [text removed for publication] secured that start in FY 2013/14.

Objective 4: ***Grow commercial activity and industrial engagement***
Our commercial and consultancy activities for a range of companies (Sec. d4) generated funding for re-investment in further research and longer term beneficial relationships (e.g. Kidde Products, [text removed for publication], Pragmatic Printing Ltd). Much of our RCUK funded underpinning/pre-competitive/low-TRL research is collaborative with industry and other organisations (also Obj. 1 and Sec. e). R&D work carried out with industrial centres of engineering excellence including Rolls Royce (funded aviation drag study), Jaguar Land Rover (EU-FP7-IAPP, auto acoustic noise reduction), Schlumberger (EPSRC first grant) and Merck Chemicals (funded LCD materials work). Four collaborative R&D EPSRC/DTI/TSB Technology Programmes in photonic and nano-materials engaged 10 companies, and we provided direct expertise and technology transfer into industry via 3 TSB supported KTP associates. Three of our on-going EU FP7 programmes are supporting 10 SMEs in prototyping products based on our technology for market launch.

b3. How future strategic aims and goals relate to the research group structure (also Sec. d3)
Our future strategy is to build out from our thematic areas of research strength via targeted investment in staff, infrastructure and grant support to realise our ambitious underpinning research goals, including, (a) Imaging: x-ray materials discrimination in solids and liquids; [text removed for publication] OCT; Portable MRI "console on a chip"; Finding/exploiting unique audio PCA signatures; Combined multiple simultaneous imaging techniques; Vibrometry of statistical variations; (b) Materials: Writing micro/nano-scale thin-film property variations; Multi-phase/sub-surface/electronic fluid flow control; Computational path-finding; New functionalised nano-structures/composites/scaffolds. ***Multi-disciplinary applications*** to be pursued in partnership (company, SME, government agency, trade association, and academic collaborators) include: Medical diagnostics/research, anti-biotic longevity, wound care and implants; Food safety/security/ conservation; Environmental reduced industrial materials/resources/energy consumption, productive re-use of waste; Efficiency in multi-phase flows e.g. oil/gas industries; Low cost larger area printed electronics; Economic product authenticity/security; Addressing/reducing marine/automotive energy needs and consumption.

We will promote the continued growth of excellent Engineering Research by: (i) Establishing an external facing Cross-Disciplinary Centre with new embedded industrial engagement/prototyping laboratories; (ii) At least 5 new academic staff appointments (including new Professor in Imaging), plus industrial liaison and experimental officer posts; (iii) Growing our international collaborations to assist in leveraging new funding opportunities; (iv) Expanding our suite of multi-disciplinary post-graduate courses building from our significant growth in Applied Sciences undergraduate numbers.

c. People: ci. Staffing Strategy and Staff Development

ci1. Evidence staffing strategy relates to research strategy and infrastructure: Strategic new appointments were made commensurate with research strategy whilst continuing to develop existing staff as excellent researchers. (a) Imaging: New niche research in applied MRI established by *Bencsik* (Reader in MRI, new submittee) with *Newton*, exploiting his expertise in electronics and acoustic sensing, and *Morris* (new Lecturer 2011, MRI relaxation) in a purpose built MRI laboratory newly equipped with 2.3 T and 0.5 T scanners; *Chappell* (new Lecturer 2012) established complementary new vibration/acoustics research. (b) Materials: Bio/nano-materials research and laboratory established by *Stevens* (new Prof 2012, from STFC) complements *Perry*'s work in bio-functional/derived/inspired materials; *Cranton* (with Koutsogeorgis) expanded into nano-plasmonics, benefitting from *Castleton's* (new Lecturer 2008) computational solid state modelling expertise. Confined flows and coating/drying research of new submittees *Ouali* (teaching contract up to 2009) and *Fairhurst* in a new laboratory (£1.8M refits and refurbishments) with *Brown* diversifying from liquid crystals into micro-fluidics strengthened solid/liquid research. *Martin* (new Lecturer 2012), with expertise in electrocrystallisation and conductivity, now works with *Wallis* on organic/inorganic hybrid materials in the new £4.4M Rosalind Franklin building (2012).

ci2. Career development support:

- Staff research mentoring was provided by Engineering Advisory Group members, along with the School Research Coordinator, to support integration of new staff and aid funding applications.
- Departmental "Research Contingency Funds" supported agreed research plans, e.g. conferences
- A share of consultancy revenue was awarded to staff via research re-investment (REF3a b1).
- Research development feedback is a formal part of annual/interim Performance Development and Contribution Review (PDCR) appraisals conducted by Department Heads, plus Dean of School for the Professoriate. A University-wide "Academic Workload" modelling tool ensured that sufficient time is dedicated to research endeavour.
- 8 of the Unit's staff received research Sabbaticals (1 Early Career, 5 × 6 months, 2 × 1 year).
- 5 further QR funded mini-sabbatical buy-outs enabled specific output/grant preparation tasks.
- The Engineering Advisory Group targeted investment of £1.2M (2009-2014) of QR income to fund PhD studentships (6 in Imaging, 7 in Materials) and 4 Research Fellow "bridging" posts.
- 9 members of Engineering staff were awarded "VC Scholarship" funding for a PhD researcher.

Examples: *Promotions* to Professorship (*Brown* 2009) and Readerships (*Liang* 2009 and *Bencsik* 2013); Lecturer *Ouali* (previous industrial/academic photonics research), appointed in 2004 on teaching contracts and to support pedagogy in our HEFCE funded CeTL, received 0.2 FTE QR funding 2010-12 and mentoring from *Newton*/*Brown* to develop new micro-fluidics research activities; Senior Research Fellow *Shirtcliffe* (now Assoc. Prof. at Hochshule Rhein-Waal) was funded by our EPSRC Platform grant to co-develop and underpin multi-project cross-disciplinary superhydrophobicity research, by Royal Society media training for associated public engagement activities, and by HEIF funds to establish Scientific Services to Industry (SS2i, see REF3a).

ci3. Implementation of the Concordat to Support the Career Development of Researchers
The University implements the Concordat to Support the Career Development of Researchers, and holds the European HR Excellence in Research Award, in recognition of its commitment to enhancing working conditions and careers for researchers. All staff regularly participate in PDCR, ensuring that staff development needs are ascertained and addressed. Researchers engage with career planning opportunities through use of the NTU Researcher Development Framework in part aligned to the Vitae Researcher Development Framework. The University "Learning and Development" Strategy applies to all staff including researchers, and includes engagement in external and internal Centre for Professional Learning and Development (CPLD) courses. The majority of our Research Fellows develop their teaching skills/portfolio with up to 3 hours per week of laboratory supervision, seminars, or lecturing (e.g. on our 3rd year undergraduate "Advanced Experimental Techniques" module), and/or co-project supervision (MEng/MSci/MChem/BSc).

ci4. Personal Research Fellowships: *Perry* held a Fellowship at the Radcliffe Institute for Advanced Study, Harvard University, U.S. for the 2012-2013 academic year (only 5% of applicants are selected each year) and also received a Wolfson Research Merit Award (Royal Society, 2013).

ci5. International staff appointments and visiting Scholars: Visiting Professors: P. Patsalas (Univ Ioannina, Greece) works with *Cranton,* Koutsogeorgis *et al.* on photonic nano-composites, with Marie-Curie researcher N. Kalfagiannis; F. Fernandez-Alonso (ISIS/STFC) assists *Castleton* on magnetic spin-lattices; R.R. Naik (Wright-Patterson AFB, USA) works with *Perry* on peptide mineral interactions. Visiting fellows: M. Krzystyniak (Krakow Univ, Poland) provides MRI/Neutron scattering expertise; D. Wilkinson (UK Inst. Physics) supports public communication. Our staff's International visiting Professorships included: *Liang* (Nat. Astronomical Observatory, Bejing, China; Univ Sci Tech of China; Raman Research Inst., India), *Martin* (Tokyo Met. Univ), *Perry* (Univ Buffalo, New York; KIT, Karlsruhe, Germany; MIT, USA) and *Wallis* (Univ Basel, Switzerland; Brock Univ, Canada).

ci6. Supporting equalities and diversity: The University adheres to and implements an "Equality and Diversity" Policy and a "Dignity at Work" Procedure, and individual circumstances are taken into account throughout management practices including recruitment, appraisal and learning and development. Our School has an Equality and Diversity Champion who participates in the Vitae Network and we are committed to Athena Scientific Women's Academic Network participation and Bronze submission in Jan 2014. All members of our Engineering Advisory Group received level 1 & 2 (Equality Challenge Unit based materials) Equality and Dignity Training. The experience profile of

our submission is balanced: 6 Lecturers (5M:1F, 1ECR); 3 Readers (2M:1F); 6 Professors (5M:1F).

c. People: cii. Research Students - quality of training and supervision of PGRs

PGRs in Engineering benefit from being part of the wider vibrant School postgraduate community. The NTU Graduate School is responsible for admissions, registration, progression, and implementing QAA/HE compliant Research Degrees regulations.

cii1. PGR Recruitment: In Engineering we adhere to the same rigorous, fair and transparent selection and recruitment policies, including Equality and Diversity, for appointing PGRs as for other staff grades, including: Open adverts on findaphd.com and subject-relevant media state minimum qualification (2(i)/1st degree) and English (IELTS 6.5) requirements with links to further details and clear additional selection criteria (Graduate School website); Interviews with the Director of Studies, Postgraduate Tutor, and another subject specialist; Skype/teleconference interviews for overseas applicants; Interview record sheet covering standardised question prompts and an analysis of training needs. Graduate School staff provide fees/funding/Visa advice, process registration, organise stipend payments, and liaise with the School's Postgraduate Representative.

cii2. PGR Support: Supervisory panels have least 2 University staff with at least two successful PhD completions between them. Our Centre for Professional Learning and Development (CPLD) runs compulsory "Research Student Supervisors" workshops, and also Independent Chair and Internal Examiner training. The School Postgraduate Tutor provides additional "pastoral" support. PGRs all have access to a desk and PC in an office in addition to laboratory facilities. PGR representatives participate as members of the School Research and University Research Degree Committees.

Training includes relevant external workshops/summer schools/conferences, the School provides:

- *Year 1 training*: Induction; 2½ day Research Methods; Project Approval workshop; Health & Safety (fume hood, gas cylinders, cryogens); 2 day Vitae "Effective Researcher"; Laboratory demonstrators training; Modules from relevant M-level programmes (e.g. www.mpags.ac.uk).
- *Year 2 training*: Transfer Report workshop MPhil/PhD to PhD; Vitae Grad School (if RCUK funded): Oral and poster presentation at the School Research Conference, a multi-disciplinary PGR training event, mixing PGRs, staff and inspiring external keynote speakers.
- *Year 3 training*: PhD Completion workshop; Careers Event; giving a talk for our Physical Sciences and Engineering internal seminar programme; Mock Viva practice.

CPLD provide courses on: online resources, publication planning, and researcher development.

cii3. PGR Progress Monitoring: Initial PGR registration is usually for "MPhil with possibility of transfer to PhD". Progress is formally reviewed at least twice per year during the registration period, including a project approval event within 6 months of registration. Annual reviews and MPhil to PhD transfer applications (PGR initiated, 12-24 months after registration) each require submission of a substantial scientific report and presentation to a monitoring panel which includes an Independent Assessor. Written feedback is provided. The University's Research Degrees Committee oversees all PGR approval, monitoring, and transfer recommendations. The successes of these policies are reflected by a high completion rate to PhD of 72% of all PGRs who commenced studies the School in 2006/07 and 2007/08 and external recognition, e.g. *G. Wells* recipient of 2009 Sharp and UK/Eire Society for Information Display (www.sid.org) Best PhD Student Award. Destinations include: Oxford Instruments (T. Miller, Process Engineer), Visteon (C. Evans, Display Engineer), Cambridge Consultants (P. Hooper, Senior Engineer), Saint Gobain (G. Boutaud, Project leader), JP Morgan (D. Willmer, financial modelling), Merck Serano (F. Martin, Quality Manager), EMD Millipore, USA (G. Tilburey); and in academia: Getty Conservation Institute US (A. Lerwill, Researcher), Keele Univ (P. Roach, Lecturer), French Nat Inst Agricultural Res (H. Adriaensen, Researcher),Taibah College of Dentistry, Saudia Arabia (M.S. Zafar, Assist. Professor).

d. Income, infrastructure and facilities

d1. Provision and operation of specialist infrastructure and facilities: (a) Imaging: *x-ray* laboratories (155m^2 floor space, 2012) with purpose-built research machines co-located with materials analysis diffractometers (Philips X'Pert Pro powder, Oxford Diffraction Single Crystal). Our Natural Science Research Centre (NSRC) *Magnetic resonance* suite (67m^2) is equipped with MRI (Bruker, 2.35 T, 72 mm), Portable NMR-MOUSE (ACT) and Halbach MRI (ACT, 0.5 T, 40

mm) machines; *Advanced optical imaging* darkrooms (109m^2) are equipped with 3D sub-surface imager (Thorlabs SROCT), Mach-Zehnder phase imager, supercontinuum Laser and x-Ray Fluorescence Spectrometer. Shared School facilities include electron (JEOL JEM-2010, JSM-840A with x-ray), confocal (Leica SP-5, DM-RBE/IRBE), and fluorescence microscopy, operated by expert technician, G. Arnott. (b) Materials: *Electronic/photonic materials* facilities (£0.35M in 2006) are co-located with new (2013) nano-materials fabrication laboratories in the 209m^2 Imaging and Display Research Facility including a class 100 clean area, lasers for thin film processing and photoluminescence (Excimer Lambda Physik 305i, Tunable NdYAG Surelite 3, HeCd CW, N2 20ns pulse), profilometers (Veeco Wyko NT110 Optical, Dektak 6M Stylus), and spectrometers (e.g. Filmetrics Reflection). *Solid/liquid interfacial science* research in 4 laboratories in Erasmus Darwin Building (166m^2) is equipped with optical tweezers, viscometers, a high voltage laboratory, laminar flow water tunnel with PIV, Krüss Drop Shape Analysis contact angle meter, high speed video cameras (Hotspot, Megaspeed, Gigaview), MaxTex QCM and a photo-lithography facility (Süss Microtech MJB4 mask aligner, thermal/sputter deposition and UV/Ozone). *Bio-materials* research is carried in two specialist biochemistry laboratories (170m^2) in our Biomedical Research facility (built 2001). *Multi-functional materials* synthesis/analysis benefits from an organic synthesis facility (204m^2, 16 fume hoods) in NSRC plus a new 103m^2 wet/dry lab in RFB equipped with materials NMR (Jeol 9.388T 400MHz). A 72 node Linux cluster supports *computational materials*, with time awards on UK (HECToR), Swedish (Kalkyl, Riolith) and US (Harvard Odyssey cluster) facilities. Specialist technician support includes S. Elliott PhD (MRI systems), D. Parker (mechanical workshop), B. Stephenson (wet bio/chemistry), N. Mould (analytical techniques), D. Edwards (cryogens), S. Burton (vacuum systems) and A. Richards (radiological systems/protection).

d2. Investment in infrastructure and facilities: During the REF period new building and development co-located all areas of Engineering research in the Science and Technology quarter of the campus, sharing facilities. Our Natural Science Research Centre (2006, £3.0M), completed near the end of the RAE period, was complemented by the brand new Rosalind Franklin building (opened 2012, **£4.4M**) and the redevelopment of the Erasmus Darwin Building (**£1.8M**, 2012/13). Examples of significant equipment purchases (>£30k, Total **£1.1M**) during the REF period include: (a) Imaging: £220k Leica SP-5 confocal microscope; £103k x-ray test-rig with Hamamatsu and Photonic Science cameras; £150k Optical Coherence Tomography (2μm, 800nm); £72k Halbach MRI; £43k Bruel and Kjaer vibrometry analysis; £32k high speed cameras; (b) Materials: £120k Oxford single crystal diffractometer; £85k x-ray fluorescence spectrometer and FLIR thermal camera (materials ID); £71k Q-Sense Quartz Crystal Microbalance and Contact Angle Meter; £66k nanofibre electro-spinning system; £56k Dantec Laser doppler anemometer for flow chamber; £34k Tecan microplate fluorescence reader; £30k microfluidics dielectrophoresis system. The library currently £186k/year invests in full text journals covering all the unit's disciplines and databases.

d3. Research funding portfolio, including future plans: Our Unit's HESA return of £7.1 Million total research income (2008/09 £1.3M; 09/10 £1.4M; 10/11 £1.6M; 11/12 £1.3M; 12/13 £1.4M), which, at £1.4M+/year is 2.1 times higher per year compared to RAE period 2001/02-06/07, reflects the successful implementation of our grant support and development strategies (Sec. b2).

Active grants with a total value of £3.5M to our Unit, with over £2.4M income due after REF census date, underpin a solid post-REF trajectory, including: (a) Imaging: x-ray (EPSRC/TSB £450k to 2016, [text removed for publication]), MRI (EU-FP7 €1.2M to 2015), Acoustics/vibrometry (EU-FP7: share of €1.4M to 2016 and €2.0M to 2015); (b) Materials: Bio-materials (US: N.I. Health/Air Force $1.05M to 2017); Nano-materials (EU/ERDF/RCUK/TSB £460k to 2016); Liquid/solid interface (EPSRC/industry/sKTP £540k to 2017). Our planned research (Sec. b3) maps naturally onto key funding priorities of RCUK, EU and US agencies. We will exploit our record of successful delivery and impact from previous such funding, and continue performing excellent underpinning research with multi-disciplinary collaborations to enable continued diversification and growth of our income.

d4. Consultancies and professional services: A diverse range of organisations have engaged our expert services, recognising our staff's knowledge and our state-of-the art techniques and facilities resulting from our underpinning research. *Brown*, co-inventor of a commercialised display technology (www.zbdsolutions.com) [text removed for publication] for Merck Chemicals Ltd (2011) and fabricated a demonstration display [text removed for publication] (2013). *Cranton,* Koutsogeorgis and colleagues have provided materials processing, fabrication and

characterisation services to Pragmatic Ltd, [text removed for publication], Quantum Filiament Ltd, Powerlase Ltd, IFire (Canada), and Semelab. *Fairhurst*'s film formation/drying expertise has been sought for pharmaceutical manufacturing development by GEA Pharma (sKTP, 2013). *Morris* MRI/thermal imaging for recipe assessment for Pork Farms Ltd (2012). *Liang* was commissioned by Fondation Beyeler (Switzerland) to inform conservation of Matisse's 'Acanthes' (2012; press release). *Newton*/*Shirtcliffe* performed coating testing/development work for Humiseal Europe Ltd (2010). *Stevens* provided expert consultancy services to STFC (Surfuzion, 2012/13), and Radius Health Ltd (2012). His contributed expertise on electrospinning technology to ESP Technology Ltd (supported by North West fund for Biomedical) and Nano Products Ltd (building from work with West Yorkshire Printing Ltd) is recognised by shares in equity. *Wallis*/*Fairhurst* provided research, advice and literature and interpretation for Kidde (www.kiddefiresystems.com) (2012).

e. Collaboration or contribution to the discipline or research base

e1. Support for and examples of research collaborations

Example 1: Bioengineering research led by *Perry* (sabbatical support for Harvard Fellowship, Sec. ci4) and Research Fellow *Belton* (supported by a regional Medici fellowship), includes: (i) peptide-mineral interactions with US Air Force funding, Univ Akron, USA, Catholic Univ Louvain, Belgium, Univ Strathclyde; (ii) dental/bone regeneration with US NIH funding, Tufts and Boston Univs. USA; (iii) Osseo-integration with Smith and Nephew; (iv) bio-silicification with Russian Institutes in Irkutsk and Novosibirsk, Helsinki Univ Finland; (v) antimicrobial nanosynthesis with Gold Council, Natl. Chem Lab, India; (vi) silica/hydrogel stem cell encapsulation with AO Research Inst, Switzerland, (vii) spider silk nan-composites with US Air Force and Tufts Univ USA (EP/E048439/1).
Example 2: *Wallis* and *Martin's* work on new organic/inorganic hybrid conducting materials with laboratories in Japan (Akutsu at Hyogo Univ, Kikuchi at Tokyo Metropolitan Univ, Mori at Univ Tokyo), France (Avarvari at CNRS Angers), Portugal (Almeida at Tech. Univ Lisbon), Spain (Coronado & Gomez-Garcia at Valencia) and Canada (Pilkington at Brock) as well as the National Crystallography and Diamond Light Source services. They participate in the UK-Japan Joint Seminars on Crystalline Conductors, and were members of the CMST COST D35 Action. *Martin's* 11 research visits to Japan since 2008 were funded by Tokyo Metropolitan Univ, Royal Society, Royal Soc. Chemistry, www.mext.go.jp/, and supported by internal QR/staff development funds.
Example 3: Solid/liquid interfacial science research on electric actuation of liquids and liquid optics [*Nature Photon*. 2009, *JAP* 2010, *PRL* and *Opt. Lett.* 2011, *Nature Comm.* 2013] with Univs. Thessaloniki in Greece (Optics), Strathclyde (modelling), Brunel (Materials), Northumbria (Engineering) was funded by: Kodak European Res. Ltd, COMIT Faraday Partnership/DTI (ICASE), Merck Chemicals Ltd UK/Germany and EPSRC (EP/E063489/1, EP/J009865/1, EP/K015192/1) with support of: Bartels Mikrotechik in Germany, Hewlett Packard, Dolomite, and L-3 TRL Ltds. *Brown* received a one year research sabbatical in 2010/11 and an internal QR funded PhD studentship (*Sampara*, 2010-13). Lab-on-a-chip techniques for ionic liquids were developed with Queen's Univ Belfast and Sheffield Univ (*Newton*, EP/D03826X/1, EP/D038995/1, EP/D038294/1) and water-repellancy properties of soils were elucidated with the School of the Environment at Swansea Univ(*Newton*, EP/H000704/1, EP/H000747/1). Surfactant research was with Univs Edinburgh (Chemistry), Warsaw (Biophysics), Bordeaux and Dusseldorf (*Fairhurst*).

e2. Support for and examples of interdisciplinary research

Example 1: Novel non-invasive Optical Coherence Tomography, hyper/multi-spectral imaging, and micro-fadometry methods developed by *Liang* (Physicist) for Art Conservation/History/Archaeology have been funded by: Fondation Beyeler in Switzerland, EPSRC (EP/E016227/1), AHRC (AH/H032665/1, CDA08/429), English Heritage, Leverhulme Trust, Nat. Museum of Ireland, Tate and National Galleries, Royal Society, Shepherd Conservation, Dunhuang Academy Conservation Inst. China, University of Science & Technology of China (visiting fellowship), RCUK (RW10-10), North West University in China (Archaeology and Conservation Dept.), Gooch & Housego plc. The work was supported by allocation of regional innovation funds (SIS 2006/07/10), internal QR funds (research assistants R. Lange, A. Lucian, 6 month sabbatical for Liang), and capital investment (Nikon XRF). Research partners included: Univ Southampton (laser physics), Shaan Xi History Museum (conservators) in China, Victoria & Albert and British Museums (curators, scientists).
Example 2: *Bencsik* (UoA B15) and *Baxter* (RAE2008/UoA33/Archaeology) discovered a highly specific PCA acoustic signature that predicts bee swarming (*Comp. Elec. Agriculture*, 2011). Following successful trails at York FERA, *Bencsik* heads the EU funded €1.4M "Swarmonitor"

collaboration (FP7-SME-2012) with EU/UK Bee Farmers Assocs. (BFA, EPBA), EU research centres (CARI Belgium, INRA France), and SMEs (Capaz Germany, Szomel Hungary, Arnia). This agreement was brokered and negotiated by the NTU Grant Capture Team. Similar principles are being developed for wolves (with Yarnell, UoA C17) and elephants (Twycross Zoo).
Example 3: The EPSRC funded Cross-Disciplinary Feasibility Account "Smart Materials - Designing for Functionality" (EP/I016414/1) was conceived/led by a University Associate Dean for Research (*McHale*) and included investigators in UoA B15 and UoA D34 (REF3a Sec. b2).

e3. How research collaborations with users have informed activities: *Cranton's* and *Stevens*' extensive industry collaborations (e.g. Plasma Quest Ltd., Johnson Matthey, Ultra Electronics, Pragmatic Printing) with RCUK, TSB and KTP funding, have enabled infrastructure expansion with specialist photonic thin-film processing and fabrication facilities underpinning new research in printed/plastic electronics and nano-plasmonic materials. *Brown*'s work on liquid dielectrophoresis was expanded into the little explored novel area of anisotropic liquids through working with world leading liquid crystal supplier Merck Chemicals Ltd (ICASE, EPSRC funding).

e4. Academic Leadership: *Bencsik* (Reader): Canadian Res. Council Reviewer (2010/11); Int. Advisory Committee "Magnetic Resonance in Porous Media" Bologna Conf series (2012-). *Brown* (Prof.): On Academic board of EPSRC/DTI MTP (GR/N29600/01, 2002-10); Chair 25th British Liquid Crystal Soc Annual Conf (2011) and Treasurer for the society (2012-); Consultancy for Merck Chemicals Ltd (2011) and Zinktech (2013). *Castleton* (Lecturer): Invited review Modelling Simul Mater Sci Eng 17, 084003 (2009); PhD Examiner at Helsinki Univ Technology and Uppsala Univ, Sweden (2008, 2010). *Chappell* (Lecturer); Invited talks at 18th Int Conf Sound and Vibration, Rio De Janeiro, Brazil (2011), ENUMATH, Leicester (2011); Programme committee member of 11th Int. Conf. on Integral Methods in Sci. Eng., Brighton (2010) and InnoWave, Nottingham (2012). *Cranton* (Prof.): Editor in Chief of Handbook of Visual Display Technology, ISBN10 3540795669, Springer Verlag (2011); Invited talks at IDTECEX "Printed Electronics Asia", Tokyo (2009) and Dresden (2010), Touch Gesture Motion Europe Conf., London (2012); Founding partner of EPSRC/DTI Masters Training Programme (GR/N29600/01, 2001-10); T.S.B. Expert Assessor (2006-). *Evans* (Prof.): Invited talks at CPNI Gordon Res. Conf., Switzerland (2013), Int. Crime Science Conf., ICSC, London (2008); Served on UK panel of experts by invitation from Chief Scientific Advisor to the UK Government (2010); Technical Director of HALO x-ray Imaging Technologies. *Fairhurst* (Lecturer): Co-Chair of Int. Conf. Wetting and Evaporation, Marseilles, France (2013) and Guest Editor of "Colloids and Surfaces A" and "Interfacial Phenomena and Heat Transfer"; Consultancy for Kidde Products (2012/13). *Liang* (Reader): Programme committee member of Int. Conf. on OCT4Art, Torun, Poland (2008), O3A, World Photonics Congress, Munich, Germany (2011, invited talk 2013), Int. Conf. Res. Conservation of the Kucha Caves, Kizil, China (2011), 1st Int. Symp. OCT for Non-destructive Testing, Linz Austria (2013); Visiting Profs. Sec. ci5; Expert reviewer for Netherland Organisation Sci. Res.(2009), NSERC Canada (2006-present), CSIR, India (2008), AHRC UK (2008); Invited review in Applied Physics A (2012); Invited talks at Inst. Conservation Conf., London (Keynote, 2009). *Martin* (Lecturer) Invited talks at MDF2012, Miyazaki, Chemical Soc. Annual Meeting, Osaka, and ISNA 2007, Hyogo, all Japan; Visiting Prof. Sec. ci5. *Morris* (Lecturer, ECR); Organiser East Mids. Packaging Soc. event (2011); Invited talk at Constructed Wetland Assoc. 6th Annual Conf., Stoneleigh, UK, (2010); Book Chapter in Meas. Tech. Wastewater Filtration ISBN 9789533072494; Consultancy for Pork Farms (2012). *Newton* (Reader): Fellow IET and Inst. Phys.; Reviewer for European Research Council (2013); Invited reviews in Soft Matter (2008, 2011), J. Polymer Sci. (2011). *Quali* (Lecturer); Invited talk at Nanyang Tech. Univ, Singapore (2013): *Perry* (Prof.); Harvard University Fellowship (2012-13), Wolfson Research Merit Award (2013) (Sec ci4); Numerous invited talks e.g. MRS, Boston (2009), SymbioMa, Mainz, Germany (2009), ACS, Boston (2010), CECAM, Switzerland (2011), MMC14, Helsinki (2011), ACS, San Diego (2012), Gordon Res. Conf. Bio-mineralisation (2012), Bionic Materials, Germany (2013); Editorships of Silicon (2010-), Nature Sci. Reps. (2012-); Panel member Deutsche Forschungsgemeinschaft (2011,13), EPSRC/NSF U.S. (2008). *Stevens* (Prof.): Founder/Research Director Electrospinning Co. Ltd (2008-); Consultancy for ESP Technology, STFC, Radius Health Ltd, Nanoflex Ltd (2012); Sapphire Prize finalist, J. Mat. Sci. (2011). *Wallis* (Prof.): Invited talks at UK-Japan Joint Seminar, Arima, Japan (2010), Graduate School and Symposium on Materials, Argonne Nat. Lab., USA (2011); Visiting Profs. Sec. ci5.