Institution: University College London

Unit of Assessment: 10 – Mathematical Sciences

a. Context

UCL's Mathematical Sciences submission comprises the two Departments of Mathematics and Statistical Science. Non-academic beneficiaries of our research include various industries, public services and their users, upon whom its impacts are felt through contributions to (among others) national security and healthcare provision, and the public through direct engagement. Major theoretical advances in areas such as fluid dynamics, and the concomitant development of powerful mathematical techniques such as 'triple-deck' theory, have enabled UCL researchers to address mathematical modelling problems arising in the aeronautical (e.g. AeroTex, QinetiQ), food (Buhler-Sortex) and sporting industries (UK Sport) as well as in medicine (e.g. Smiths Medical). These studies have, in turn, delivered economic benefits to our industry partners, for instance through cost savings and the improved products for their users, who include Olympic cyclists. [text removed for publication]. The strong emphasis in Statistical Science on multi-disciplinary research in areas including biostatistics, medical imaging, spectroscopy and statistical modelling in the physical sciences has delivered tools such as stochastic models for rainfall that are used by DEFRA, and risk calculators for heart surgery that are influencing clinical practice. It has also and been used to improve methods for calibration implemented in the software of an instrument manufacturer (Foss). Furthermore, public engagement with the Mathematical Sciences is viewed as a key aspect of knowledge transfer, with audiences benefiting through improved understanding of mathematical concepts.

b. Approach to impact

Collaborative research with industry - with whom we work with closely on the application of mathematical and statistical approaches to solving their problems - constitutes our primary pathway to impact. To help guarantee and maximize the relevance and utility of our work to industry partners, the Unit encourages staff **membership of and contributions to forums for the meaningful exchange of ideas with non-academic partners**. Researchers within the UoA are highly engaged with Knowledge Transfer Networks: Smith and Kurylev, for example, are members of the scientific committee of the Industrial Mathematics KTN, which provides a key forum for the transfer of information and ideas allowing us to ensure the relevance of our research to industry needs. Wherever possible, we also create our own opportunities for productive dialogue with existing and potential users. To that end, for instance, the financial mathematics group (established September 2012) recently brought together academics and members of the financial industry by hosting a 3-day conference on algorithmic and high frequency trading at UCL (April 2013), attended by some 25 industry representatives. Beyond taking and creating opportunities to learn more about our non-academic partners' need, the Unit has taken a multifaceted approach to building and maintaining relationships conducive to meeting those needs. These approaches have particularly included **encouraging interdisciplinary research**, our contacts and engagement with industry frequently stemming from our determination to promote and foster inter- and cross-disciplinary collaboration. Accordingly, we have favoured candidates with a track record of interdisciplinary research in appointing a number of new staff in Mathematical Sciences since 2008. In Mathematics, Zaikin, a mathematician whose research interests span systems biology and medicine, was appointed jointly to a Chair with the UCL Institute of Women's Health in September 2008. His work has led to the development of a new method of identifying proteasome peptides (a core part of human immune systems); this has delivered particular benefits to our partners in medical research and, subsequently, to clinical practitioners and patients. A recent new joint appointment (Ross) between Statistical Science and UCL's Institute of Risk and Disaster Reduction will strengthen an existing collaboration the focus of which has so far been the quantification of uncertainty in natural hazard prediction. Unit staff also played leading roles in establishing the multi-disciplinary UCL Centre for Inverse Problems (2013) to develop mathematical, numerical and statistical techniques applied to inverse problems arising in medical imaging, computer science and geophysics. Two new lecturers (Oksanen and Kiraly) were appointed in summer 2013 in support of the centre. As well as enhancing our engagement with - and therefore our capacity to deliver benefits to - industry, our emphasis on and appointment of staff with interdisciplinary interests has also formed the basis of **increasing engagement with clinicians and the NHS**; in several

instances this has been bolstered by joint appointments between Statistical Science and our partner hospital, UCLH. The first such appointment, specifically intended to encourage interactions between methodological statisticians and biomedical researchers was of biostatistician Omar in 2000. Further appointments have followed of biostatisticians Ambler and Barber (NHS funded) and, since 2008, Baio (joint with NHS); van den Hout and de Iorio (HEFCE funded) have added to this strong team. These appointments have supported increased engagement with medical practitioners and, as a result, led to impacts on clinical practice. Thus, for example, a risk assessment model for cardiac surgery developed by Omar and Ambler is beginning to influence clinical practice. These sorts of impact are furthered by our Clinical Operational Research Unit (CORU). Formally part of Mathematics, CORU is dedicated to applying operational research and mathematical modelling approaches to problems in health care. Projects include work with local NHS organizations, those informing national policy, and international partners working on global health problems: their mathematical and statistical modelling of the number of women giving birth without a skilled attendant in each country in South Asia and sub-Saharan Africa over the next five years will inform short-term policy.

The **transfer of highly skilled people**, as well as of expertise, between the UoA and its external partners is another important strand of our approach to impact. Mathematics has a growing record of supporting periods of **secondment or sabbatical leave** [text removed for publication]. Not only is the Unit happy to facilitate this, for example by rearranging teaching duties, it also supports secondments *into* the department. Mathematics, for instance, hosted a Royal Society Industry Fellow (Curtis, QinetiQ and DIEM Consulting Ltd) who worked with Smith for 12 months in 2009-10. **Industry-sponsored studentships** are also an important method for our transfer of skilled people supporting the development and maintenance of partnerships with industry. Since 2008 and as part of the KTN network, 4 PhD students have undertaken internships with QinetiQ, National Grid, VR Technology and Unilever, with supervisors ER Johnson, Csornyei (a pure mathematician), Ovenden and Smith respectively. We use these sorts of opportunities to create new and consolidate existing industry relationships whilst applying our research expertise (via research students) to particular problems within partner organisations. Johnson's PhD student, for example, who was seconded to QintetiQ for 7 months in 2010-11, adapted methods developed in his PhD research on coastal waves to study the use of ultrasonic waves for non-destructive testing. Mathematics has also had 4 EPSRC CASE studentships since 2008, with the Met Office (2 studentships, supervisor Davey), TotalSim (supervisor Smith), and pharmaceutical company Astellas (supervisor Smith). Fostering industry links through studentships is facilitated centrally by the UCL-wide Impact Awards scheme, which supports collaborative PhD studentship projects with charities, companies, government institutions and social enterprises by providing 50% funding, contributing £32K towards the cost of a 3-year PhD. Girolami has two UCL Impact studentships, both with with industrial partner Xerox Research. Nelson has a PhD student sponsored by Defence Science and Technology Laboratory (DSTL) working on detection of hostile cyber activity, and an Impact studentship funded by DSTL. In alignment with UCL's public policy strategy, a mathematics PhD student spent 7 months in 2012 on secondment to the Department for Business Innovation and Skills (BIS) using EPSRC knowledge exchange funding for policy secondments. A second PhD student has embarked on a similar 4-month secondment to BIS from August 2013. Nelson leads a TSB/EPSRC Technology Inspired Innovation PDRA project on "Smart sensor network for powerline monitoring using machine learning" (2013) and a further PDRA project on mine counter-measure funded by DSTL.

Shaw's appointment in 2011 as Professor of Mathematics and Computation of Risk (joint with UCL Computer Science) catalysed the initiation from 2012-13 of two new MSc programmes in Mathematical Finance and Financial Risk Management (the latter joint with Computer Science), as well as three new appointments in Financial Mathematics. The MSc programmes exploit natural and geographically convenient relationships with the City and act as conduits for research engagement, including through joint academic/industry seminar programmes and joint student supervision. OpenGamma (a financial software company), for example, led a 15-lecture programme at UCL for London MSc and PhD students and industry practitioners (15 participants), and student research projects are jointly supervised with financial industry practitioners such as Deutsche Bank. The Centre for Computational Statistics and Machine Learning (CSML) receives funding from Winton Capital, Amazon, Bupa, DeepMind, Featurespace, IBM research, Microsoft research, NCR Labs, Select Statistics and Xerox Research. DeepMind sponsors CSML's

Masterclass series in which leading researchers visit UCL to present their research to academics and representatives with interest in machine learning (e.g. mobile social gaming technologies).

As well as transferring highly skilled staff and expertise to industry, the Unit's approach to impact encompasses our **provision of expert advice**, particularly to policy-making and strategic advisory groups, an activity whose value is formally recognised via appraisal and promotion processes. To that end, Chandler is a member of the Volcanic Ash Advisory Group, set up to advise the UK government on volcanic ash risk to aviation [text removed for publication]. Isham was President of the Royal Statistical Society (2011-12). Her role there included providing advice to government on a range of issues, and she was relieved of all teaching duties for two years to facilitate this. Wilson attends meetings of the Parliamentary and Scientific Committee, following recommendation by their Advisory Panel. From 2013, Macrina has joined the advisory board of the African Collaboration for Quantitative Finance and Risk Management and has presented seminars at the South African Reserve Bank and the Rand Merchant Bank.

The final key strand of our current approach to impact is **engagement with the public.** Research staff are encouraged to communicate both directly with the public and to contribute to media discourse stimulating debate and encouraging interest in the discipline. Kurylev contributed a session on his work on invisibility and cloaking, for example, to the 2008 British Festival of Science in Liverpool. Boehmer has presented talks on general relatively (including reference to his own research results) to school groups, including at the Meet the Mathematicians event at UCL in 2012 (attended by 130 school students). Lotay gave various popular science talks to 6th form students, including two in 2012, titled "Maths in Action", to audiences of over 800 students each time. Mathematics runs an annual "Women in Mathematics" day, which features research-based talks by staff members (e.g. Zerbes and Wilson in 2013) and PhD students. Staff also contribute to UCL's public engagement initiative, "Bright Club", which challenges academics to deliver stand-up comedy routines based on their research for public audiences: Lotay's routine, based on his research on 7-dimensional geometry, featured twice in 2012 with audience numbers greater than 100 on each occasion. He also spoke about his appearances at Bright Club on Radio 4's Word of Mouth programme in 2012, and appeared on film as part of the event "The Science Stories" at the forum discussion tents at two festivals (Secret Garden Party and Wilderness) in summer 2012.

Structural and institutional support for impact: Knowledge Transfer (KT) is one of four key criteria in promotion at UCL. This provides incentives for staff to explore industrial collaborations and participate in public engagement wherever possible. The Unit is committed to upholding the importance of KT and to making success in this area a factor in its consideration of promotion applications. Setting KT objectives is explicitly included in all staff appraisals: for example, Boehmer's recent successful application for promotion to Reader contained a strong element of public engagement activity. More broadly, UCL recognises the importance of activities relating to and impacts arising from Enterprise with an annual award ceremony: in May 2013 Smith won the annual UCL Provost's Spirit of Enterprise Award for his longstanding commitment to industrial collaboration. Both departments have appointed Enterprise coordinators whose role includes making other staff aware of opportunities for external collaboration and helping colleagues build upon these collaborations with support from UCL's Vice-Provost (Enterprise). We also draw on the support offered by UCL Business PLC (UCLB), a wholly-owned subsidiary of UCL formed to help industry and business make the most of the University's innovations: Guillas, for example, has recently been provided with teaching relief to carry out a proof of concept study for a tsunami prediction model, with support from UCLB.

c. Strategy and plans

The Unit's strategy and plans for achieving future research impact revolve around both sustaining and expanding successful facets of its current approach and developing new methods for engaging and delivering benefit to external research users.

- UCL's mathematical science's commitment to multidisciplinary research, for which UCL provides many opportunities and which has naturally formed the basis for much of our impact so far, will be maintained and enhanced by further staff recruitment to interdisciplinary posts. To that end we will, where appropriate, continue our policy of favouring candidates with a track record of interdisciplinary research, including in Biostatistics, inverse problems, and computation.
- We will also continue to capitalize on opportunities to build new and consolidate existing

relationships via industry-sponsored studentships, internships and secondments; [text removed for publication]. The Unit further plans to increase industry engagement through the expansion of CASE studentships and KTN partnerships; a studentship is being negotiated with the European Office of Aerospace Research (Smith).

- We will continue to routinely grant sabbaticals to work in organisations like GCHQ, and to take advantage where possible of centralized support from institutional KT funds and UCLB, including for policy secondments and proof-of concept funding.

As well as maintaining and expanding these successful strands of our existing approach, the Unit plans to develop and deliver a number of **new initiatives and mechanisms** promoting and enhancing its research impact:

- A new programming club for staff and students will start in 2013-14, supported by a £5K grant from UCL Advances, UCL's centre for entrepreneurship. The club will have a particular focus on "apps", with industry experts giving technical talks and providing mentoring to help staff develop new ideas in this area. Those with "apps" worthy of further development will benefit from expertise and advice provided by UCL Advances, including their provision of training on topics such as "How to become a confident & effective networker" and "Communicating Science to Business".
- An important part of UCL mathematical science's overall research strategy is to raise its UK and international profile. One aspect of this is to expand public engagement activity and, where possible, to use online and social media to deliver wider impact from work such as Bishop and Fry's London riot modeling.
- Building upon the successful introduction of the UCL Mathematical Finance group, Mathematics will be advertising for two new lecturer/senior lecturer positions in Financial Mathematics in autumn 2013. An important part of the person specification will be the ability to build and enhance the links we have built in recent years with the London finance community.
- Wolfe's work on networks and big data is attracting interest from commercial organisations such as dunnhumby and Channel 4, with the latter already having sponsored what is intended to be the first of several PhD students. This is an area that Statistical Science plans to grow.
- Betcke and Lotay, together with the 2 PhD students seconded to BIS, will produce a briefing document providing policy-makers with an accessible explanation of the value of mathematics research to them. This will give clear and concise explanations of relevant examples of Mathematical Sciences research at UCL, explaining their achievements, benefits and pertinence to policy makers. We plan to invite the Head of Research Funding at BIS to give a presentation at UCL on research funding policy and to present him with the briefing, with the goal of stimulating further policy engagement.

d. Relationship to case studies

The primary mode of realizing impact in the Mathematical Sciences at UCL has been through **direct engagement with industry** and other external partners. This approach is exemplified by the case studies on aircraft safety (UCL10-SMI), environmental noise (UCL10-OVE), radon gas exposure (UCL10-FEA) and decision-making in the power sector (UCL10-SID). Researchers often became aware of the problems addressed by their research in these case studies through our strategy of **encouraging and facilitating interdisciplinary research**. The same is true for the case study involving health impacts in clinical outcome monitoring (UCL10-UTL), where techniques were developed in response to specific issues raised by the health services and discussed with UCL mathematical scientists. Our policy of **embedding knowledge transfer** as a core aspect of academic activity has led to an increase in public engagement with Mathematical Sciences and its applications, audience enthusiasm for which is reflected in Fry's case study on public interest in modelling the London riots of 2011 (UCL10-FRY). The importance of **providing expert advice to policy-makers** as part of our knowledge transfer strategy is evident in Chandler's case study (UCL10-CHA). This describes the development of theoretical tools with previously only limited applications into tools used widely by insurance companies and governments interested in simulating climates in order to inform their policies**.**