Institution: Loughborough University

Unit of Assessment: B10 Mathematical Sciences

a. Context

The Unit of Assessment B10 of Loughborough University is based in the Department of Mathematical Sciences. Its research covers a broad spectrum of mathematics and its applications. It is organised into six research groups (Dynamical Systems, Geometry and Mathematical Physics, Global Analysis and PDEs, Linear and Nonlinear Waves, Mathematical Modelling and Stochastic Analysis).

Research by the Unit has led to impact particularly in the energy and health-care sectors, with interactions with a number of companies in these sectors. Activities within this area include contributions to energy demand reduction, working with Asahi glass; materials for photovoltaic applications, with Applied Multilayers and Pilkington glass; and on materials for power generation with companies in the nuclear sector, including Rolls Royce, EDF and AWE. Within the health-care sector the Unit has made contributions to the design process for analytic instruments produced by Thermo Fisher Scientific and used in many hospitals and laboratories in the UK and worldwide. In addition the Unit works with industry in the areas of complex fluids and on the interaction of waves with structures.

The Unit's research has also benefited other academic disciplines such as physics, chemistry, biology, environmental science, chemical engineering, material science and finance. This is part of a journey towards possible direct impact in the future.

b. Approach to impact

Over the period of REF 2014, research and enterprise activity has remained at the heart of Loughborough University's strategic plan "Towards 2016". Staff in the Unit are encouraged to work with the five interdisciplinary Research Schools at the University level, to ensure that advances in mathematics are embedded in the applied disciplines. An example of the impact of this approach is the EPSRC funded project of Prof Smith and Dr Kenny in collaboration with Applied Multilayers and Pilkington glass, of which the ideas came from a Materials Research School workshop.

Direct engagement with business is another approach to deliver the impact. An illustration of this is the work of Dr Kenny as director of HPC Midlands, one of the five EPSRC-funded regional e-infrastructure centres, who has worked extensively with the University's enterprise office to engage with businesses regarding their utilisation of high performance computing. In preparing the successful bid, Dr Kenny made full use of institutional facilities in the Enterprise Office to identify partners and build the business case. A full-time business development manager is employed to drive the engagement and help with knowledge transfer from the University into businesses. It currently has contracts with three companies for time on the system and is in negotiations with a further eighteen companies, providing an invaluable resource to industry.

The University has initiated a 'leaders in research' initiative whose remit is to develop research leaders with cross-disciplinary expertise. The Unit has actively engaged with this as part of the strategy for developing impact. Dr Mazzocco has used this opportunity to explore the possibility of applying moduli space techniques to RNA and protein folding and to liaise with the Health and Life Sciences research in the University. She organised a cross University workshop to develop new areas where mathematics could underpin novel science and engineering leading to impactful projects. This has led to Dr Mazzocco being appointed as Deputy lead in the Health and Wellbeing Research Challenge area within the University. The Unit will encourage staff to continue to use

such opportunities in the future.

Staff are encouraged to maximise the impact of their research outside of academic beneficiaries. An example of this is use of the work by Dr M. McIver and Prof P. McIver on non-uniqueness in linear water-wave problems to develop a series of severe test cases for the computer software WAMIT. This software is produced by a company formed by researchers originally at MIT and is extensively used by the offshore industry.

Impact is also supported through public engagement. For example, Prof Kurylev (now at UCL) gave a popular lecture at the 2008 British Science Association Festival on the mathematical theory of invisibility and cloaking devices, following a seminal Physical Review Letters paper (PRL, **99**, 183901 (2007)). This theory attracted substantial media interest, including publications in *Nature, National Geographic* and *Wired* magazine.

Staff working on fundamental research are also encouraged to look for opportunities for possible applications of their results. Some real world applications have already occurred in a serendipitous manner as one of the outcomes of the active research in the Department (which is evidenced for example in Case M4). Staff members are actively engaging with potential users when opportunities arrive. For example, Dr Bolsinov is currently involved in the designing of robotball, a new type of vehicle, in collaboration with Udmurt State University and industry in Izhevsk, Russia. Dr Hunsicker works in collaboration with the Wolfson School of Mechanical and Manufacturing Engineering at Loughborough University and Prof Nistor from Penn State on a project to improve the imaging of microscopic surfaces with edges and corners using tools from singular analysis.

On the more applied side, Dr Ward is currently working with industrial partners at Syngenta and Unilever on the development of new drug testing protocols. The aim is to reduce the cost and accelerating pre-clinical trial process through the reduction and more effective use of animals in toxicological studies. He is also engaged with researchers at the Institute of Animal Health (Pirbright, Surrey) on the pathology of foot and mouth virus disease in order to improve disease management in livestock.

Support for impact is also achieved through the two MSc courses that the Unit runs: Industrial Mathematical Modelling (IMM) and Mathematical Finance. The IMM MSc course provides students with techniques that are widely used in industry and has compulsory projects, of which the majority involve the student being seconded into industry. These projects have led to innovation such as software developed in conjunction with 3M for modelling asthma inhalers and software used by Jaguar cars for modelling hybrid car switch-over times. All these students are assigned both an industrial and an academic supervisor with people from industry taking part in marking the student projects. Many of the students involved in these projects continued to work for the sponsoring companies, such as 3M and GL Noble Denton. The Unit is currently engaging with institutional mechanisms to leverage further partners for this initiative and to enhance the impact opportunities.

The Unit also supports impact directly through the part funding of PhD projects involving industry, through either its internal funds or EPSRC Doctoral Training Grant studentships. This has allowed the Unit to grow a number of industrial collaborations through the REF period by allowing companies to see the impact that Mathematics can have on their business.

c. Strategy and plans

The Unit is taking a number of approaches to the development of impact arising from its research. These range from offering staff members opportunities to develop skills necessary to carry out impact activity to supporting partially industrially funded projects. The latter is an approach that the Unit has already pursued for a number of years and will remain a key component to developing the

reach and significance of the impact the Unit makes. Recently this has helped kick-start projects with both AWE and Asahi Glass; with the AWE project now fully funded.

Another component of the Unit's approach to impact is to encourage staff with potential for impact to engage with the University's Research Challenges, which align with national imperatives. Working with interdisciplinary teams will help impact activity undertaken in the Unit to move up the technology readiness ladder. In addition, the Unit plans to apply for Knowledge Transfer Account (KTA) funding to enhance links with industries.

The development of staff is an important part of the Unit's impact strategy. To achieve this the Unit plans to use the mentoring available from the University's Enterprise Office to help staff to successfully engage with industry.

The Unit supports research activities potentially leading to case studies by allowing relevant staff extra flexibility with teaching and administration duties to support the development of impact. Impact of research is now an item in individual staff member's research plan. The progress and opportunities in this direction are discussed at the meetings of individual staff with the Head of Department and Head of Group as part of the annual Personal Development Review.

d. Relationship to case studies

The four case studies selected for submission illustrate how the Unit's approach to impact works.

Cases M1 and M2 have arisen due to a flexible use of Unit funding to facilitate the initial work with industry and the establishment of the potential for impact. These cases have then been allowed to grow through the Unit being flexible in its allocation of duties to the staff involved and funding for PhD students. These case studies were a result of applied research with direct links with industries.

Case M3 and M4 had grown from a more theoretical research of the top experts in the nonlinear waves and dynamical systems areas. Prof Grimshaw was directly engaged with industry-supporting research institutes such as Woods Hole in the USA. Case M4 was a result of interaction of Prof Neishtadt with Thermo Fisher Scientific, one of the leading companies producing mass spectrometers. In both M3 and M4 cases, the Unit has supported the researchers by giving financial support and extra flexibility for their time.

All impact case studies resulted from the active research and interacting culture in the Department. They demonstrate that impact of mathematics research can occur in a variety of ways and exemplify the importance of the breadth of the research base in the Department of Mathematical Sciences. This will remain as one of the main parts of the impact strategy of the Unit.