Institution: City University London

Unit of Assessment: 10 Mathematical Sciences

a. Context

Research in Mathematics at City University London was originally based in the School of Mathematics. In 2002 the University took a strategic decision to strengthen its engineering and business and management activities by transferring some staff to the Cass Business School, while the remaining Mathematicians transferred to a Centre in the School of Engineering & Mathematical Sciences. This new structure allows for a more efficient exploitation of mathematical theory in Engineering applications while the group which joined Cass, comprised of actuaries, statisticians and operational research specialists, benefited from closer collaboration with finance and management colleagues. Strong links have been maintained between the two groups. Two of the submitted impact case studies stem from this relationship.

The very general nature of the research carried out by most of the Mathematics staff means that long lead times are normally required before impact is realised. The type of impact and groups of beneficiaries can vary considerably. During the assessment period, economic and health impacts have been achieved along with impact on practitioners and professional services.

Mathematicians in the fields of Operational Research and Statistics have directed their expertise in Combinatorial Optimisation and Bayesian networks to software applications which simultaneously achieve social and economic impact. The wellbeing and quality of life of staff in the health services and in call centres has been improved in conjunction with savings for the employers, through greater care and efficiency in deployment of staff from optimised rosters. This also contributes to compliance with legal frameworks such as the European Working Time Directive. Further impact for practitioners and professional services has been achieved through the development of software which establishes the degree of familial relationship between two or more individuals, through DNA profiling by the Home Office, the judiciary and the police.

The main type of impact resulting from the research carried out in the Mathematical Physics Group is economic. The Group carries out basic theoretical research in quantum mechanics and quantum field theory, but traditionally some of the work also has a very applied phenomenological aspect. Theoretical prediction is followed by experimental verification, leading to concrete industrial application. The predicted effect of tunneling magnetoresistance for a specific material changed the technology and type of read head devices for hard discs to such an extent that worldwide, all three companies involved in their production today use the findings. The principal beneficiaries are high-tech companies, in particular IBM and the Tsukuba group during the development stages and Western Digital, Seagate and Toshiba for the final commercialisation.

The main area of impact for the newly-founded Mathematical Biology Group (established in 2010, with two of the current members joining in 2012 and 2013) is on public policy and services. The group members are experts on game theory, stochastic processes and network theory, all areas of Mathematics which in principle support very concrete applications. The work of Dr Kandler on the conservation of endangered languages has already informed local government policy-makers in Switzerland, Scotland and the USA.

The Representation Theory Group is exploring opportunities for applications of its fundamental research. For example, Dr De Visscher is investigating the consequences of her breakthrough work on the Kronecker Problem for the famous P vs NP Problem, the solution of which would have a significant effect on the global economic infrastructure, benefiting banks in particular.

b. Approach to impact

The substantial changes in both staff and areas of research focus which have taken place since 2008, alongside an increased emphasis on impact from research in the University's Strategic Plan 2012-2016, have provided the basis for a more systematic approach to impact. Previously opportunities have arisen following the publication of research results in leading international peer-reviewed journals. A recent University policy decision requires the deposit of full text for all research articles published since January 2013, such that a greater exposition of published results is provided through search. The Department has led the University in depositing articles, with 378 uploads at November 2013, with an associated 8,145 full text downloads out of a total of 142,999.

The published articles have triggered the interest of potential beneficiaries who have subsequently established contact with the members of staff concerned. Staff are provided with support for further exchange with the users to cater for their specific needs and to facilitate impact. With work in magnetoresistance, as is often the case with Mathematical Physics research, the research findings fed into further experimental verification carried out by others, which in turn created opportunities for commercial development.

Our public dissemination of research also benefits from the University hosting The Conversation UK (http://theconversation.com/uk), where UK academics write about their research for a lay audience.

In this context the Department has recognised the need to enhance its capacity to create impact more effectively. It seeks to establish interactions with non-academic groups and potential beneficiaries at a much earlier stage of the research rather than waiting for publication, in order to influence its direction and maximise its impact.

The following steps have been taken to achieve this:

a) *Building on staff expertise*, by considering the potential contribution and experience of academic staff to achieving impact from research during the recruitment process. Examples include Dr Kandler, Dr Baronchelli and Dr de Martino.

b) *Increasing the awareness of staff of the potential impact of their research*. This has included participation by members of the Department in industrial partnership workshops organised by the School of Engineering & Mathematical Sciences, to provide information on specific needs and requirements of beneficiaries. Staff are also encouraged to participate in the wide range of Enterprise activities organised by the University.

c) *Using public media to increase the awareness of the public and potential beneficiaries of the research*. Dr Kandler's work on language shift was covered in newspapers and science journals such as *The Scotsman* and *Discover Magazine*. She was also interviewed by BBC Scotland Newsnight. Three members of the Mathematical Physics Group, Professor Fring, Dr Castro-Alvaredo and Dr He, produced short videos in February 2013 about their current research published on the media platform *Faculti Media*. Professor Fring's video has become the most watched physics video on that platform (over 4,300 views).

d) *Encouraging staff to engage in multi-disciplinary work*, particularly with Engineering and the Cass Business School, to bridge the gap between theoretical prediction and direct applications. The developments in spintronics made it clear that the capacity to support experimental aspects of the research in house would be very beneficial. Closer working relationships have accordingly been established between members of the Mathematical Physics Group and experts on photonic systems in Engineering who can contribute to further developments in the field of spintronic systems.

e) *Recognising staff engagement in activity which supports impact from research* in both annual appraisal and promotion procedures and through workload management processes which provide time for such activity.

c. Strategy and plans

The Department will benefit from the University's new Framework for Achieving Impact from Research and Enterprise, which supports the approach outlined above and includes:

Addressing the potential for impact from research in proposals for funding. Academic staff will be assisted by the University Research Office in considering potential and strengthening their proposals to meet funder requirements for impact, thus also raising awareness among staff while preparing funding proposals.

Encouraging and enabling research activities which facilitate the co-production and application of knowledge beyond the University and thereby generate impact, including collaborative or commissioned/contract research projects with companies, government bodies and other organisations and with individual research users.

Encouraging and enabling staff to use research results in the provision of consultancy services to companies, government bodies and other types of organisation.

Developing and training staff and students by raising awareness at all levels of the importance of research impact. Academic and research staff will benefit from training to support impact activity from public engagement through to the commercialisation of research. Doctoral students will also receive training and support to enable them to understand the importance of research impact and

to develop skills to enhance the impact of their research and equip them for the workplace post-graduation.

The Department's recruitment strategy and the accompanying expansion have both supported and increased applied research, thus providing a strong basis for potential future impact. In addition to the continuation of the mechanisms outlined in section b above, there are three major strands to the strategy for enabling further impact from research in the future:

a) *Building on the Department's successful track record in spintronic systems*. The modern, cutting-edge version of these systems is ideally realised via the spin-orbit coupling in graphene, such that graphene is now recognised as the perfect building block for future spintronic devices. A focus on this area therefore has strong potential for further economic impact. In order to gain more specific expertise in this field, in 2012 the Department recruited Dr de Martino, who possesses a track record of original research in graphene systems. These new activities are firmly embedded in the existing research carried out in the Mathematical Physics Group on quantum systems and quantum field theory. This also aligns with the European Commission's selection of graphene as one of Europe's first 10-year, €1 billion Future Emerging Technology flagships. An application for funding in this area will be strengthened by the School's Engineering expertise.

b) *Strengthening the Mathematical Biology Group with a strong focus on applied research* and with expertise in game theory, stochastic processes and network theory, providing opportunities to generate impact across a broad range of beneficiaries. Dr Kandler has brought to the Department a track record of generating impact on public policy. New strands of her work on the conservation of endangered languages will be pursued, in particular in response to declared interest from governmental organisations in Switzerland and Scotland. Dr Baronchelli's cutting-edge work on predicting human search patterns of network users such as Twitter and Facebook provides immediate commercial applications with potential impact in the health and economic domains.

c) *Rebuilding of the fluid dynamics group* in the Department offers opportunities for collaboration and cross-fertilisation with the computational fluid dynamics group in Engineering, in particular in the areas of low speed aerodynamics. Given the successful track record of that group, this interaction is likely to produce further economic impact.

d. Relationship to case studies

The impact described in the spintronic case study results from work which is integral to the research activities of the Mathematical Physics Group both past and present. The lead author of the case, Professor Mathon, has been a member of the Department since 1970. He has served as Head of Department and is still engaged as a part-time researcher (0.2 FTE). The achievements detailed in the case study have informed the Department's approach and strategy as outlined above to build further on the successful track record in spintronic systems. The Group has been enlarged with currently nine members carrying out research in this area.

The second and third impact case studies both demonstrate how complex mathematical techniques can be used to support developments which are of direct practical application in society. They further demonstrate how academic staff can work directly with users to tailor the application of their findings so that the ensuing impact is strengthened. All three cases provide valuable experience upon which to base the Department's strategy for impact. In particular the clear potential for additional impact arising from the work in spintronics has informed the type of increase in staffing in the Mathematical Physics Group and the focus on closer collaboration with Engineering colleagues referenced above.