Submission to the Dowling Review

Introduction

We welcome the opportunity to contribute to this important Review from the viewpoint of the mathematical sciences. This submission has been prepared by the heads of (in alphabetical order)

- the Council for Mathematical Sciences www.cms.ac.uk
- the International Centre for Mathematical Sciences www.icms.org.uk
- the Isaac Newton Institute for Mathematical Sciences www.newton.ac.uk
- the Smith Institute for Industrial Mathematics and System Engineering www.smithinst.co.uk
- the Turing Gateway to Mathematics www.turing-gateway.cam.ac.uk

Brief accounts of their missions are appended.

The reason for this submission is to draw attention to the mathematical sciences[1] and to the opportunities they offer for creating high returns on investment for the UK. For example, mathematics is essential in data analytics, risk and uncertainty management, and the design of high-performance products. However the effective management of mathematics in creating successful business-university collaborations is different from other disciplines.

It is important here to distinguish between the routine use of mathematical techniques which are pervasive across science and technology, and the potential impact of adopting a holistic mathematical perspective at the heart of business. The latter is the focus of this submission.

The UK will lose a competitive edge if it does not harness effectively the well-established world leading mathematical capability of its universities. Other countries (South Korea is a good example) have recognised this opportunity and are investing heavily in their mathematics infrastructure.

In March 2011 the REF2014 team published its approach to Impact and in November 2012 the Deloitte Report on the Economic Benefits of Mathematical Science Research in the UK[2] was published, concluding that the contribution to the UK economy is 16% of GVA.

Responses to the Review Questions

1. *What experience do you have of establishing, participating in or supporting long-term research collaborations between business and academia?*

CMS develops, influences and responds to UK policy issues that affect the mathematical sciences in higher education and research, and therefore the UK economy and society in general. It commissioned the Deloitte report on the economic benefits of mathematics mentioned above.

SI has active links with around 25 leading research universities, which it assists in creating new collaborations (over 120 in the last 5 years). Until March 2014, SI managed the successful KTN

[1] We use "mathematics" and "mathematical" as shorthand for the mathematical sciences, which include pure and applied mathematics, probability and statistics, and theoretical computer science

[2] http://www.epsrc.ac.uk/newsevents/pubs/deloitte-measuring-the-economic-benefits-of-mathematical-science-research-in-the-uk/

for Industrial Mathematics on behalf of the Technology Strategy Board. It operates across the full range of business sectors, to harness the cross-cutting value that mathematics can deliver.

INI has for many years hosted Open for Business events and, in March 2013, launched the TGM to facilitate the flow of knowledge and ideas from the mathematical sciences to potential users and to bridge the gap between mathematicians and business, government, and other academic disciplines.

ICMS is extending its established programme of knowledge transfer activities (some in conjunction with TGM and SI) to support the mathematics community in its interaction with industry and business.

ICMS, INI, SI and TGM all aim to achieve high leverage on funding through timely business-focused partnerships in areas of high priority and high impact.

2. *What are the key success factors for building productive, long-term research partnerships between business and academia and how do these vary across sectors and disciplines?*

It is important that academics recognise that business collaborations offer novel and rewarding mathematical challenges and they need opportunities to present what they have to offer. Successful research partnerships exhibit strong 'co-creation', in which all partners make significant scientific contributions to an outcome that could not have been achieved in isolation. Without a collaborative ethos, relationships become 'supplier-consumer' interactions, which serve other purposes but do not create strong research partnerships. We argue that existing incentives, policies and funding streams for such relations, which may work well in other disciplines, are not well suited to mathematics.

In summary, the key success factors are:

(a) Mutual enthusiasm and incentives for building new relationships
(b) Availability of the necessary skills and expertise
(c) Shared visions of how a relationship develops to mutual advantage
(d) Access to funding mechanisms at the points of greatest need
(e) Personal relationships and results that are regarded as successes by both sides.

3 & 4. *What barriers do individual businesses face in developing long-term research collaborations with academic partners and how can these be overcome?*

What barriers do academics and universities face in developing long-term research collaborations with businesses and how can these be overcome?

Enterprises may not realise that mathematics has a role in their activities and, even if they do, often have no awareness of how to find and connect to expertise, or obtain funding.

Although SI, ICMS, TGM and many universities are active and effective in facilitating partnerships, the scale of the challenge in mathematics is higher than in other disciplines because the subject is highly granular, with many pockets of relevant expertise that are difficult to match quickly to industrial requirements.

Very few organisations have a view of their own capacity to interact with mathematics, even when their internal structures highlight expertise in other scientific disciplines. The consequence is that 'champions', with the drive and incentives to create relationships with mathematicians, are not actively encouraged.

Given the focus on building trusting relationships, it makes sense to look at barriers to building relationships that will affect both sides, which are naturally paired with the success factors listed above.

(a) **Generating enthusiasm for collaboration.** A major barrier is mutual lack of awareness between universities and businesses of what a shared ambition could yield. Because it is unusual in mathematics for industrialists and academics to be research partners, there is no existing culture of co-creation that characterises the most strategic business-university relationships, for example in engineering. Contract negotiations can also prove laborious. Designing simple contracts where possible is advantageous.

(b) **Skills and expertise.** The ability of business to absorb mathematics is probably depressed by the legacy of low numbers of school leavers taking Further Mathematics a decade ago. In 2013, over 22,000 pupils took AS Level Further Mathematics, compared to fewer than 4,000 in 2004. Consequently a cohort is moving through the workforce with little working familiarity in mathematics. This is happening precisely at the time when mathematics is needed to exploit opportunities in areas such as data science.

(c) **Shared visions and lack of expectation.** Few enterprises and universities view mathematics as an intellectual asset with the capacity of being exploited commercially. INI, SI, TGM and ICMS devote considerable effort to raising the profile of mathematical through success stories, and the recent introduction of REF impact case studies has also concentrated minds. Nevertheless, low expectations and/or low visibility compared to other disciplines remains a major barrier to developing shared visions.

(d) **Access to funding.** For some disciplines, high capital investment is needed to pull new research from low to high TRL levels. By contrast, the competitive edge of mathematics is in its ability quickly to create new or improved products and services without high capital costs. The challenge is to identify and act quickly on opportunities to gain first-mover advantage.

The range and impact of collaborations would be increased if agencies such as InnovateUK could address the point of greatest need, namely support for early-stage collaborations, so that trusted relationships and shared visions can take shape. This is also true of the Research Council Impact Acceleration Accounts (IAAs), which support exploitation of established RCUK-funded research – but that is not the usual life-cycle of academic/industrial activity.

(e) **Short-termism.** A further barrier for academics and universities is business emphasis on short-term results, rapid personnel changes or changes of responsibility in some businesses. These points can be overcome by responding to a short-term goal to provide an immediate return, and by forming relationships with more than one person in the business.

5. (A) *How effective are current incentives, policies and funding streams for promoting this type of collaboration?*

(B) *How could these be improved in order to scale up the range and impact of collaborations being undertaken nationally?*

The incentives in academia are growing, e.g. HEFCE funding for good REF impact case studies and EPSRC requirements for Pathways to Impact. There are also longer-standing ones like Industrial CASE studentships, EPSRC Industry Fellowships, secondments and partnerships, follow-on fund, Royal Society Industry Fellowships, feasibility awards and awards for innovation, 1851 Exhibition Industrial fellowships, and PhD studentship competitions offered by Microsoft and IBM.

We are less certain about the incentives in business; if a collaboration will produce short-term advances then it is straightforward, but long-term requires company leadership at senior level. InnovateUK provides financial support that makes collaboration more viable, but the bureaucratic overheads can be problematic.

Regarding specific mechanisms, we have the following comments:

Knowledge Transfer Partnerships (KTP)

In July 2014, there were 767 current KTP Programmes, of which 18 had mathematics as their knowledge/technology area (info.ktponline.org.uk, retrieved 24 February 2015). However, of these 18, fewer than half were based in departments of mathematics or statistics. The uptake of KTP to support collaboration with the mathematics research base is therefore barely more than 1% of the total portfolio, and has been for over a decade. The percentage of science students graduating in the mathematical sciences is about 5% at first-degree level (www.hesa.ac.uk), and so mathematics is under-represented among KTPs. The KTP model is simply not suited to mathematics, because it does not target the point of greatest need. (See recommendations below.)

Collaborative PhD projects

Last year, a dozen new Centres for Doctoral Training (CDTs) were established in various branches of mathematics, with some having strong emphasis on industrial engagement. The signs are promising that these CDTs will have a positive effect in making mathematics more accessible and more visible to potential collaborators. There is also a risk that they will draw attention away from institutions that have excellent collaborative credentials, but no CDT. The mathematical research landscape has historically been highly fragmented, and initiatives such as CDTs are, for better or for worse, consolidating activity into a smaller number of larger centres.

EPSRC's industrial CASE programme places PhD funding with companies that have strong records in collaborative research. The difficulty is that hardly any of these awards support collaborations in the mathematical sciences, because of lack of awareness of the opportunity within companies.

Catapult Centres

The Catapult Centres have been created to help the UK secure market share in areas of emerging and often disruptive technology. To be successful, they need to leverage UK capacity and capability and to create critical mass on a global scale. It is not clear how well the Catapults in general are incentivising collaboration. However, our institutes have engaged with some of the more well-established ones (Transport Systems, Satellite Applications and High-Value Manufacturing).

A strength of the Catapults is that they are not constrained by the historical ways of doing things. They have much to gain from harnessing mathematics to accelerate innovation. However, it is inefficient for each Catapult to do this independently, especially when they have little awareness of the existing relevant mathematical knowledge. It would be better if there were a single shared mathematics facility on which all Catapult Centres could draw. (See recommendation below.)

HEIF

For mathematics, it is important that there should be funding for cross-institutional interaction with the commercial sector, not just in each individual university separately. It is difficult to make the variety of different connections with universities that may be needed. HEIF is useful but its single-institution focus represents a missed opportunity. This remark pertains also the Impact Acceleration Accounts.

More general suggestion for scaling-up collaborations are:

- Reduce the bureaucracy of InnovateUK grants.
- Promote standard frameworks for university-business contracts.
- Fund initiatives for promoting mathematics-business collaboration.
- Support mathematical Study Groups with industry.
- Provide grants for both academics and businesses to attend relevant conferences, for example those hosted by CMS member societies.

6. *How can progress under the Industrial Strategy be harnessed to stimulate collaboration between businesses and researchers in the UK?*

The Industrial Strategy should focus not just on physical infrastructure, but also on intellectual infrastructure, i.e. the skills that underpin strong collaborations. This needs to be accompanied by an incentive for cross-disciplinarity, including mathematics.

Recent BIS analysis found that the UK exhibits “a sustained, long-term pattern of under-investment in public and private research and development and publicly funded innovation”. The impact of this long-term under-investment on business-university collaboration is probably not yet fully apparent, but if it were to continue it is likely that companies (especially multinationals) will tend to shift the balance of their interactions outside of the UK. Mathematics is an area where relatively low levels of new investment, carefully targeted, could mitigate these risks.

It would be hugely beneficial to identify clearly the areas in the Industrial Strategy where mathematics can contribute, so that organisations like ours can more actively promote the associated opportunities to mathematicians. (See recommendation below.)

7. *Which models of collaboration have proved most successful for stimulating SME engagement with the research base in the UK? What additional action needs to be taken to strengthen UK performance in this area?*

SMEs generally require interactions that have rapid turnaround and low barriers to entry. In mathematics, there is a long track record of successful SME participation in Study Groups, and also through Industrial Mathematics Internships[3]. In both of these approaches, it is crucial that SMEs are supported at all stages, especially when preparing the ground to give the best chance of success. To engage, SMEs only have to write a short description of their interests and requirements, in the natural language of their own application domains.

8. *Which approaches/sectors/organisations – in the UK or internationally – would you identify as examples of good practice in business-university collaboration with the potential to be applied more widely?*

The Industrial Mathematics Knowledge Transfer Network, which ran from 2005 to 2014, and its predecessor, the Industrial Mathematics Faraday Partnership (2000 and 2005) were run by the SI with support from DTI, ESPRC and the TSB, and were highly effective at creating new collaborations. The KTN was successful because it fulfilled four strategic requirements:

- it was a national initiative, able to build an active network of 100s of organisations;
- it had an explicit focus on mathematics, so was able to raise expectation and visibility;
- it could to create funding streams where they were most needed.
- It knew its academic community intimately

The Industrial Mathematics KTN attracted a great deal of international attention as a model of good practice, including in France, New Zealand, Malaysia and Brazil.

As a means of raising awareness, the IMA's Mathematics Matters Case Studies[4] have been highly influential. They provide examples of the application of mathematics to industry, society and the economy, showing how mathematics research influences so many areas of modern life.

Recommendations

Recommendation. We suggest that a facility should be established for Catapult Centres to gain advantage from relevant mathematical expertise that would otherwise go untapped. It should be of a size relative to the Catapult network that roughly reflects the size of mathematical activity within the overall science base. A budget of about £3M/year would support a team of

[3] Study Group and Internships provide fast results through highly focussed engagement on innovative business opportunities identified by companies. See www.smithinst.ac.uk.
[4] www.ima.org.uk/i_love_maths/mathematics_matters.cfm.html

30-40 mathematical scientists. This new facility would be charged specifically with ensuring that all the Catapults have the benefit of the best available mathematical know-how.

Recommendation. A large-scale, national programme should be built up to give early career researchers in the mathematical sciences direct experience (over 3-6 months) of how business R&D operates and to boost dramatically the pipeline of new collaborations and case studies. The Smith Institute's experience (more than 100 projects) in this area could serve as a foundation on which to build, along with some of the activities in CDTs and elsewhere.

Recommendation. In developing the Industrial Strategy, BIS should resource a joint study with the mathematics community to elucidate the areas in the Strategy where mathematics can contribute most strongly. These opportunities should be matched to the strengths in the UK's mathematical research base, and disseminated through a joint report. In this way, government can act as a catalyst for the raising of expectations across academia and business and for boosting the impact of mathematics in the areas of greatest importance to the UK.

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Appendix: Contributors

The Isaac Newton Institute for Mathematical Sciences (INI) is a national research facility for the mathematical sciences which is based in Cambridge, which aims to contribute to the research landscape at a level which is consistently internationally leading.

The International Centre for Mathematical Sciences (ICMS) organises research workshops in mathematics and related areas. Its Knowledge Transfer Officer identifies potential users of new mathematical ideas from outside the academic community. ICMS also performs a crucial role for the mathematical community in northern Britain by organizing and hosting meetings for special interest groups, by undertaking editorial and production work on mathematical journals for learned societies, and by providing administrative support for the Scottish Mathematical Sciences Training Centre.

The Smith Institute for Industrial Mathematics and System Engineering (SI) leverages mathematical know-how to create value for business. It works extensively with the research base and Research Councils, to deliver programmes of effective business-university interaction. The Institute's operational model is regarded as an example of international best practice.

The Turing Gateway to Mathematics (TGM) addresses critical needs for the transmission of mathematical knowledge to areas where it is needed. Working closely with INI, it has a proven record for delivering an interdisciplinary agenda.

The Council for the Mathematical Sciences (CMS) comprises the Institute of Mathematics and its Applications, the London Mathematical Society , the Royal Statistical Society, the Edinburgh Mathematical Society and the Operations Research Society.